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TERMINAL TREATMENTS FOR ILLINOIS CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

By

Jagat S. Dhamrait and Richard K. Taylor

Interim Report
IHR-36
Investigation of Continuously Reinforced Concrete Pavement

A Research Project Conducted by
Illinois Department of Transportation
Springfield, Illinois 62706
in Cooperation with
U. S. Department of Transportation
Federal Highway Administration

June 1977

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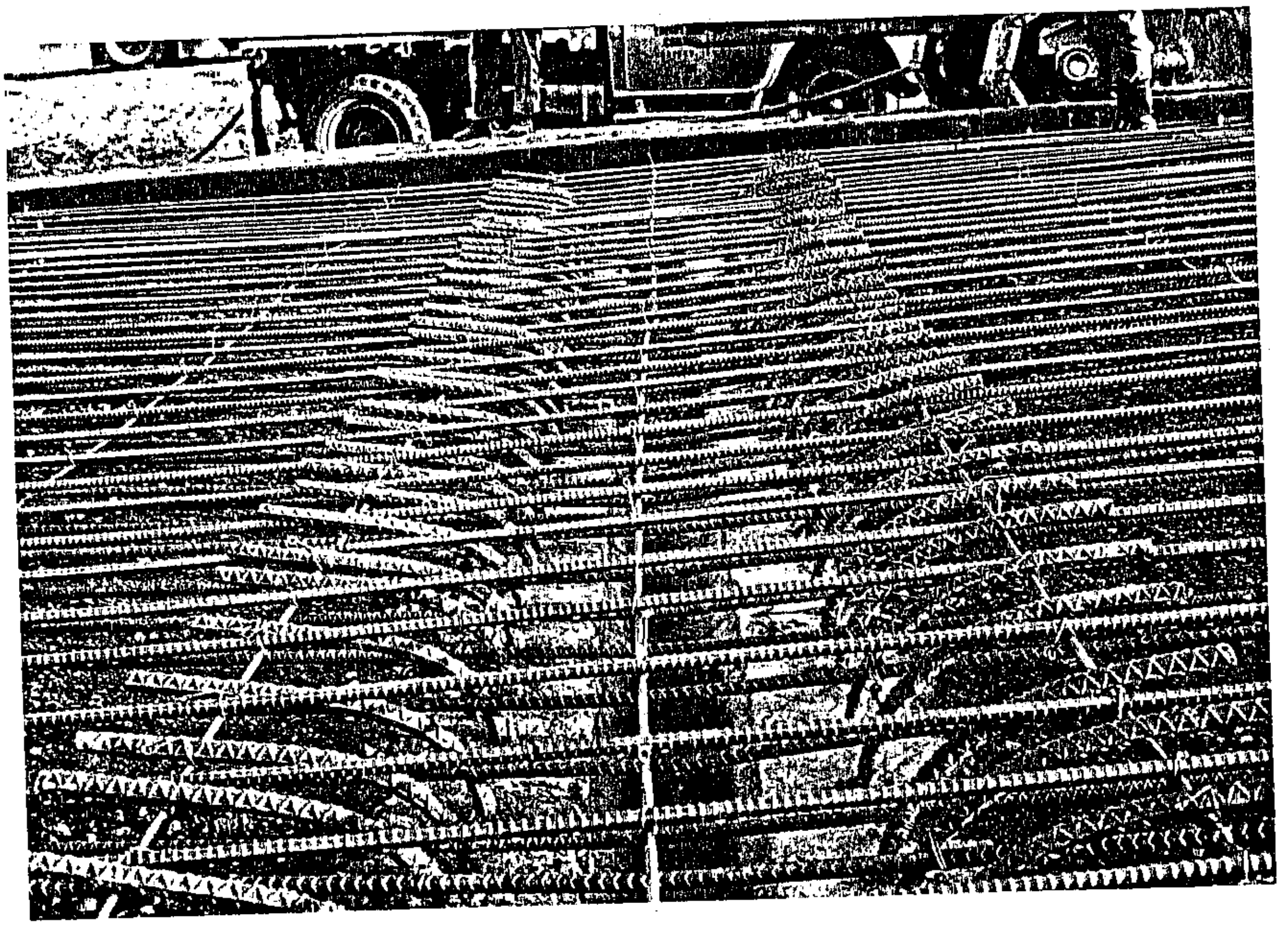


Figure 3. Anchor Lug Construction

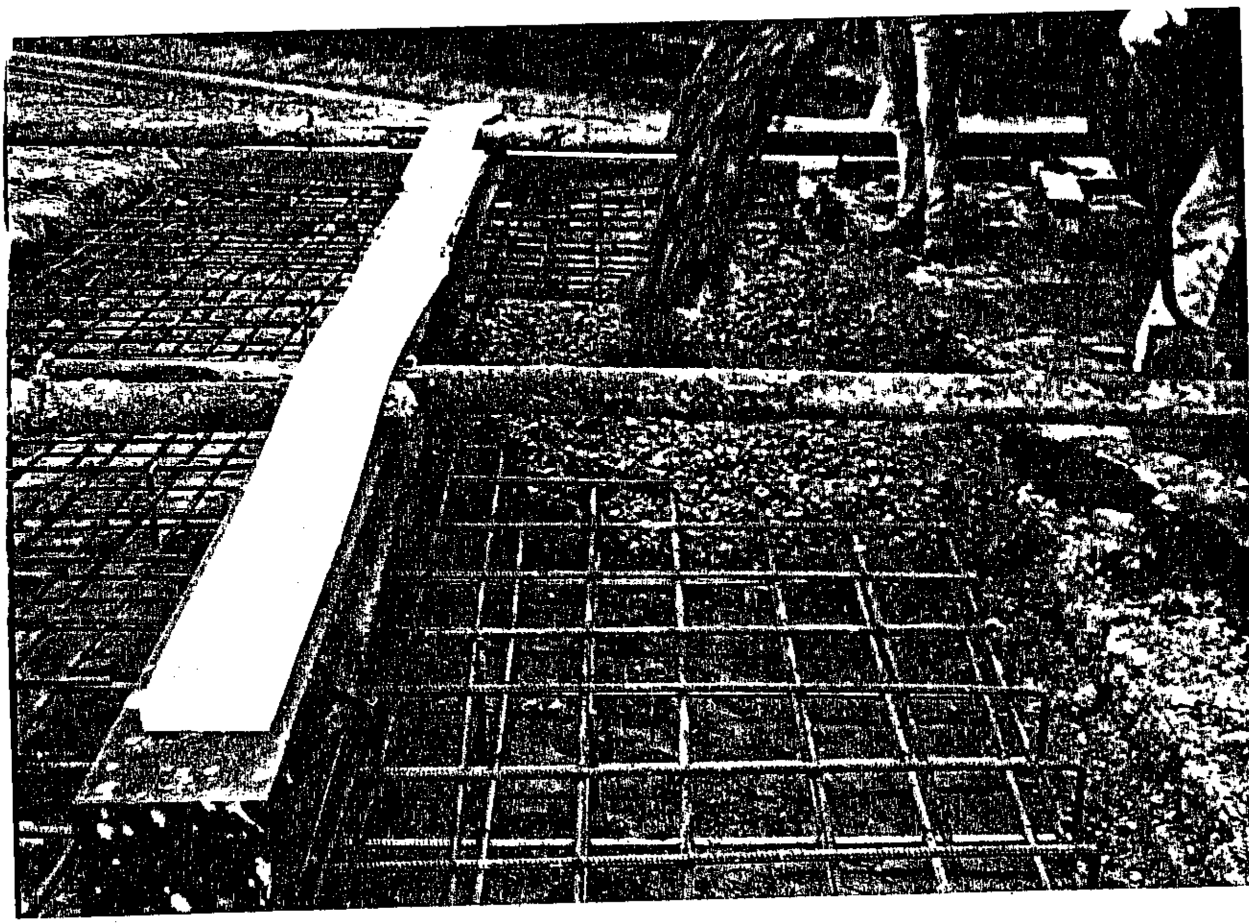


Figure 5. Wide-Flange Terminal Construction

Figure 16. Distressed Anchor System Before Excavation

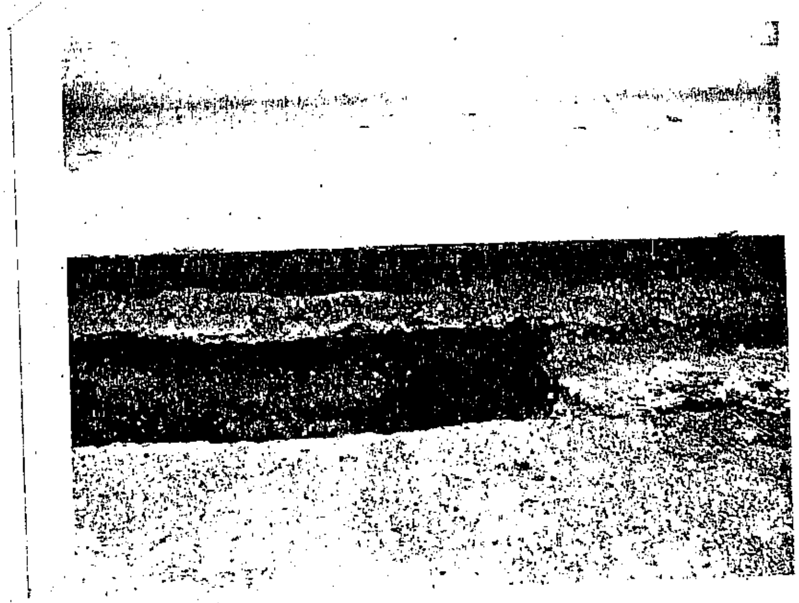
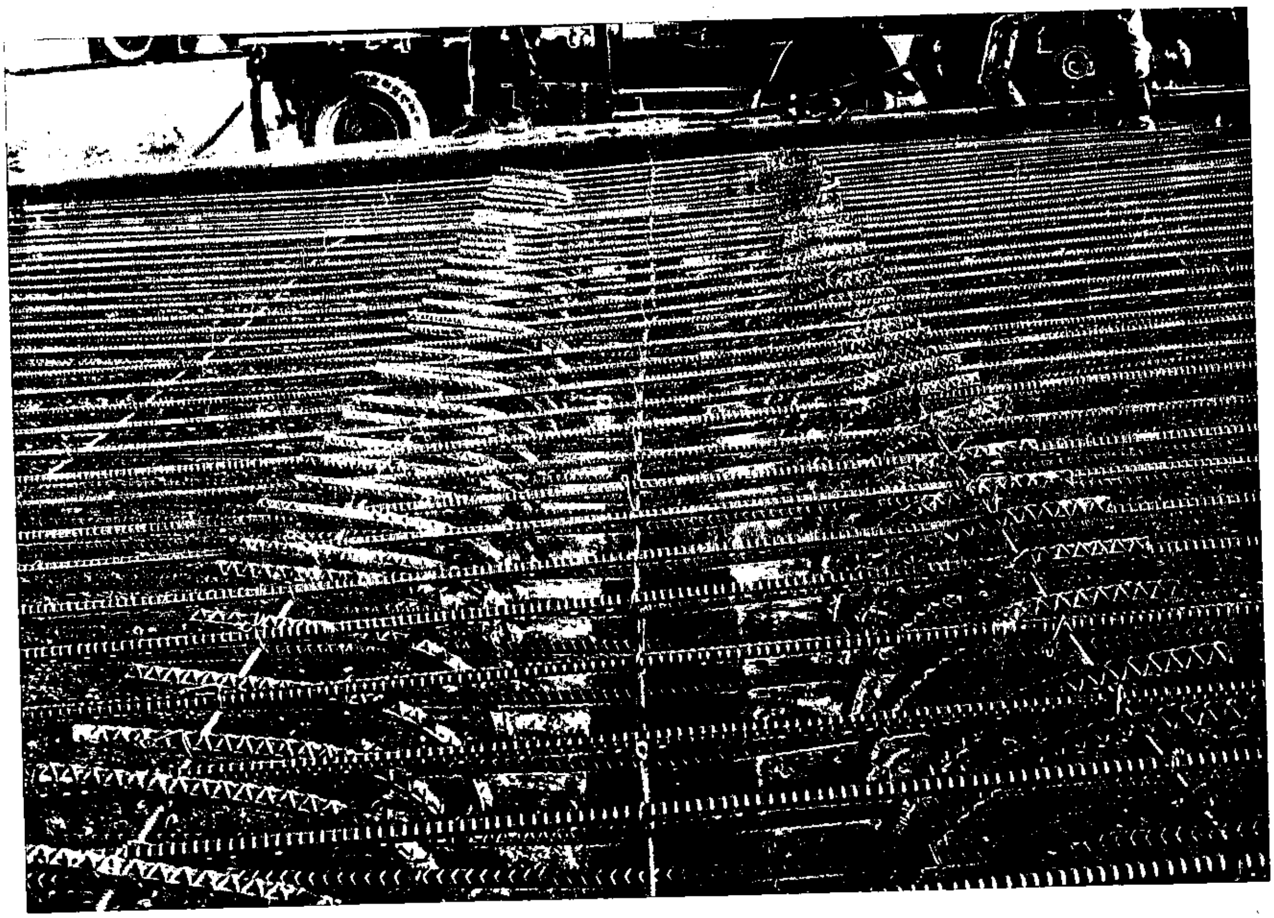


Figure 17. Distressed Anchor System After Excavation
(Showing void next to lug wall at lug 1)



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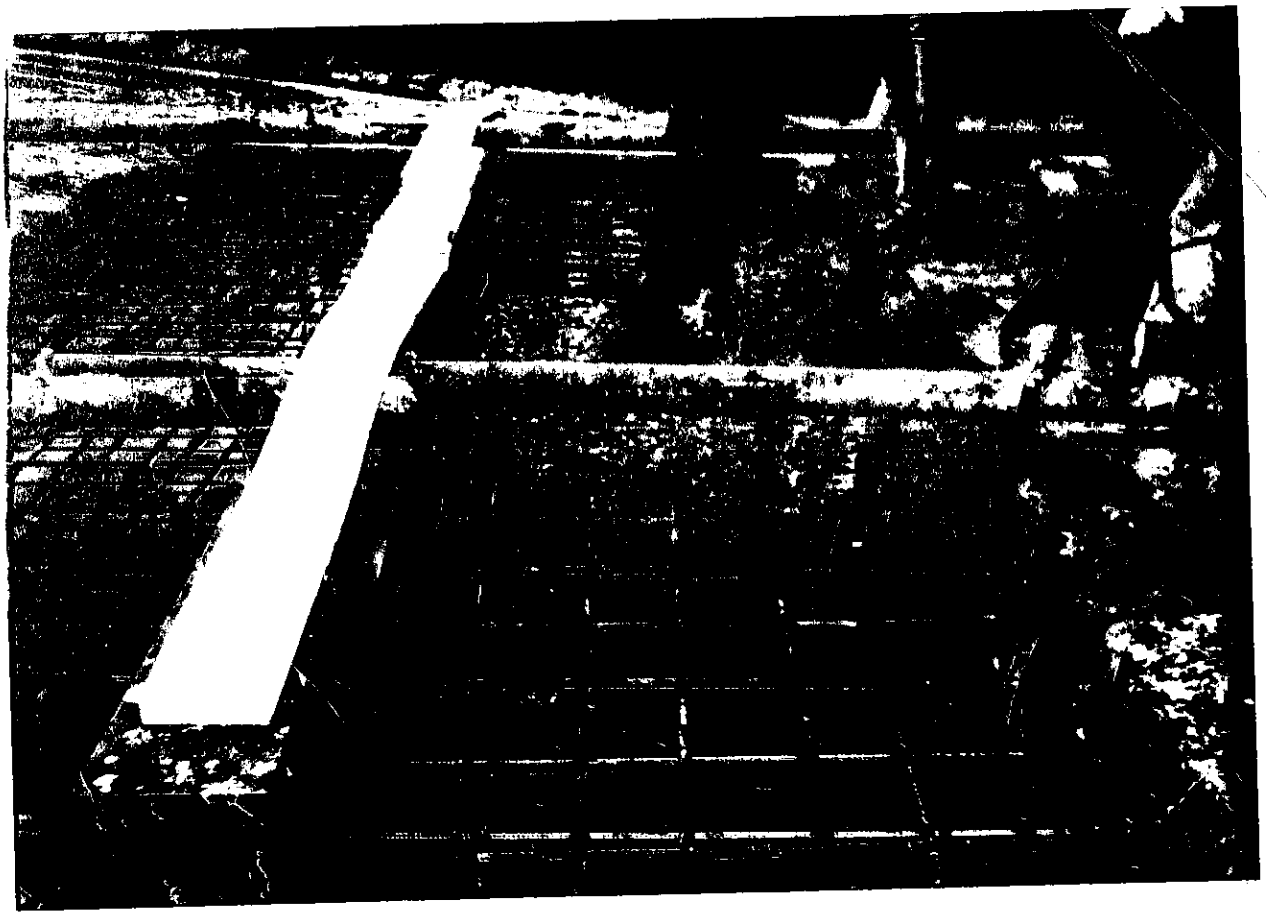

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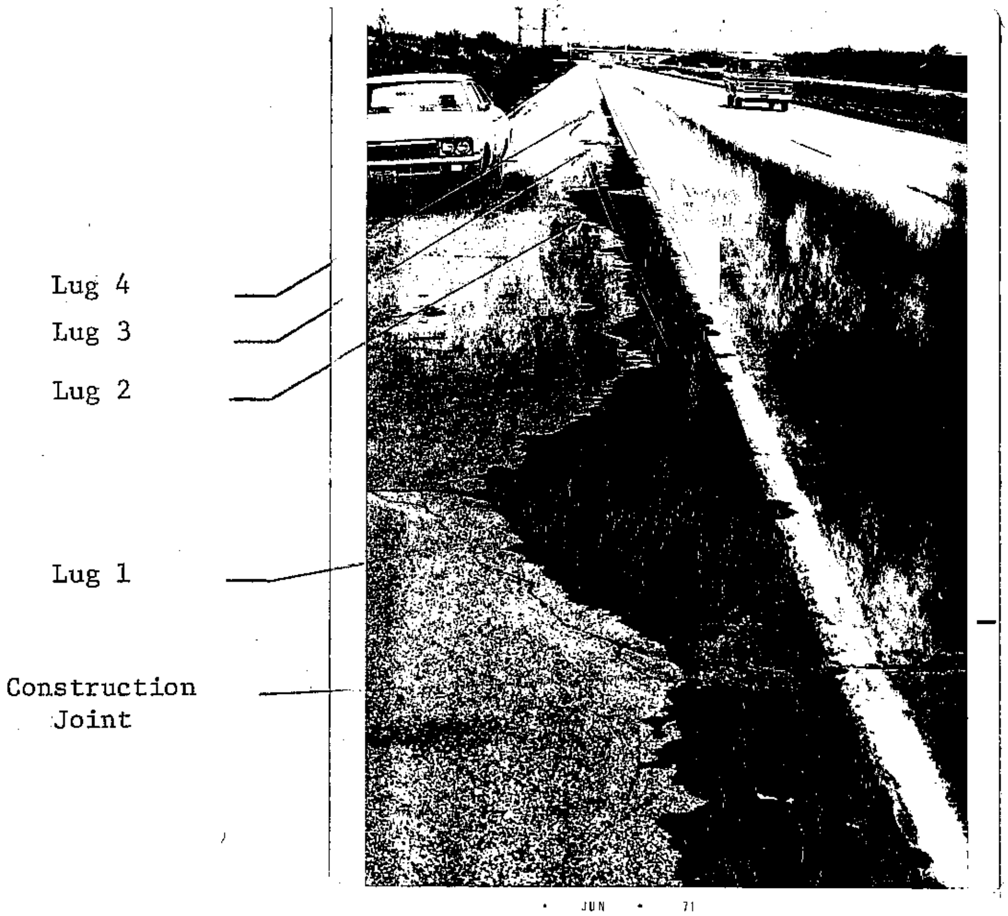

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16. Abstract As part of an extensive study conducted to determine the significant relationship between the behavior of CRC pavement and various design features, an evaluation was made of several types of anchor lug systems and terminal joints. Movement of the ends of CRC pavements can exert damaging forces against bridge structures and adjacent conventional pavement. To prevent this type of damage, some type of terminal treatment is necessary at each free end. A terminal treatment can be designed either to restrain the movement (an anchor system) or to accommodate the movement (a terminal joint system).

Because the optimum number and spacing of anchor lugs for various soil conditions and subbase types were not known, the number and spacing of lugs were varied at different locations in the State and the behavior of the various lug arrangements were compared. All combinations of lug spacing and number of lugs appear to have been effective in partially restraining the pavement movement, however, distresses in the lug area have developed at some locations.

In an effort to find a less costly yet satisfactory method of alleviating the effect of end movements, ten wide-flange beam terminal joints were constructed at two locations. The data indicate that the terminal joint provides an effective method of accommodating the movements at the ends of pavements at a lower cost than restraining the movements with anchor lugs.

17. Key Words CRC pavement, anchor lug systems, terminal joints, crack spacing, repair of distressed lug areas.	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

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FOR
ILLINOIS CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

INTRODUCTION

The effect of end movement of continuously reinforced and conventional portland cement concrete pavements due to changes in the environment and/or mechanical stress, has been causing concern to pavement designers for many years. Experience with continuously reinforced concrete (CRC) pavements indicates that longitudinal expansion or contraction is limited to the free ends of a long slab. Other studies have indicated that most of the movement takes place within 300 to 500 ft (91.4 to 152.5 m) from the ends of a slab (3,6). The center portion of the slab is restrained by the frictional force from the subbase. The free ends occur at a bridge or railroad crossing as well as the beginning and the end of a pavement slab.

The magnitude of the annual movements occurring at the free ends of CRC pavements normally may be expected to be within 1 to 2 in. (25 to 51 mm); however, movements exceeding 2 in. (51 mm) have been reported (1,2). Movements of this magnitude can exert damaging forces against bridge structures or against adjacent conventional pavement. To prevent this type of damage, some type of terminal treatment is necessary at each free end. A terminal treatment can be designed either to restrain the movement (an anchor system) or to accommodate the movement (a terminal joint system).

Full restraint of all the movement at pavement ends would be extremely costly and difficult to achieve. Therefore, an anchor system which would partially restrain the movement in combination with a joint designed to accommodate the remainder of the movement would seem to be a reasonable alternative. Other studies have indicated that the restraint provided by lug anchors of reasonable design reduce the movement of pavement ends by about one half (3).

This study was undertaken to evaluate the effectiveness of lug anchorage systems, and wide-flange beam terminal joint systems, and to develop information which will permit refinement of the design standards and specifications.

Illinois' experience with CRC pavements began in 1947-48 with the construction of an experimental CRCP on U. S. Route 40 near Vandalia (1). The experimental pavement is 5 1/2 miles (8.9 km) long and divided into eight test sections, six of which are about 3,500 ft (1066.8 m) long and two of which are about 4,200 ft (1280.2 m) long. The 4-in. (102 mm) expansion joints, which separated the test sections from one another and from the conventional pavement adjoining each end of the experimental pavements, were installed so that each section would have considerable freedom to change length independently. In the early years following construction, reasonable movements of 1 to 2 in. (25 to 51 mm) between summer and winter were recorded; however, by the summer of 1957 all of the expansion joints were tightly closed. Large spalls indicative of excessive compression were observed at several of the joints and major repairs were required. Subsequent patching has been required at almost all of these expansion joints. Due to these failures and the high cost of maintaining the joints, a different approach for solving the problem of end movement for concrete pavement in general, and continuously reinforced pavement in particular, was believed to be necessary.

In 1961, the Illinois Department of Transportation began an intensive study of continuously reinforced concrete pavement in cooperation with the Federal Highway Administration. The study included construction of several experimental sections of continuously reinforced concrete pavements throughout the State to determine the significant relationship that exists between pavement behavior and certain design variables. Also, the study included the construction and evaluation of several types of anchorage systems. The study was first described by Dhamrait, Jacobsen and Schwartz in a 1973 report (4). A second report describes the construction experience (5). Since details of the study are fully described in these reports, repetition of basic information has been purposely avoided in this report except where necessary for better understanding of the results.

The design features to be evaluated in this study include anchorage systems of various configurations. The design of anchor lugs is based mostly on engineering judgment. Because the optimum number and spacing of anchor lugs was not known, it was decided to vary the number and spacing of lugs at different locations, and compare the behavior of the different anchor arrangements. A series of transverse rigid concrete lugs in conjunction with at least three expansion joints were constructed at each terminating point of the pavements.

At the time the original work plan for the study was formulated it was believed that winter-to-summer movements of approximately 3/4 in. (19 mm) or less at the anchors would indicate satisfactory performance of the anchor lugs. Based on this criterion, the end anchorage systems appear to have performed relatively well in partially restraining the pavement ends. The anchor lugs required little maintenance; however, initial construction costs were relatively high.

In an effort to find a less costly yet satisfactory method of alleviating the effect of end movement, wide-flange beam terminal joints were constructed at two locations involving a total of 10 terminal treatments. The function of such terminal joints is to accommodate a free movement of the pavement ends rather than to restrain them.

This report describes the evaluation of the lug anchor systems and terminal joint systems with the following findings. Annual winter-to-summer movements of all lug systems averaged 3/4 in. (19 mm) or less. In some cases there was a tendency for the lug anchor systems to move slightly outward with age. All combinations of lug spacing and number of lugs appear to have been effective in partially restraining the pavement movement; however, distresses in the lug area have developed at some locations. The wide-flange beam terminal joint data suggest that this type of terminal treatment is an effective method of accommodating the movements at the ends of pavements at a lower cost than restraining the movements with anchor lugs. No significant relationship between the annual movement and age was established, but there appears to be a tendency for slight permanent growth of the pavement ends toward the beams.

DESCRIPTION OF SITE CONDITIONS AND CONSTRUCTION PROCEDURES

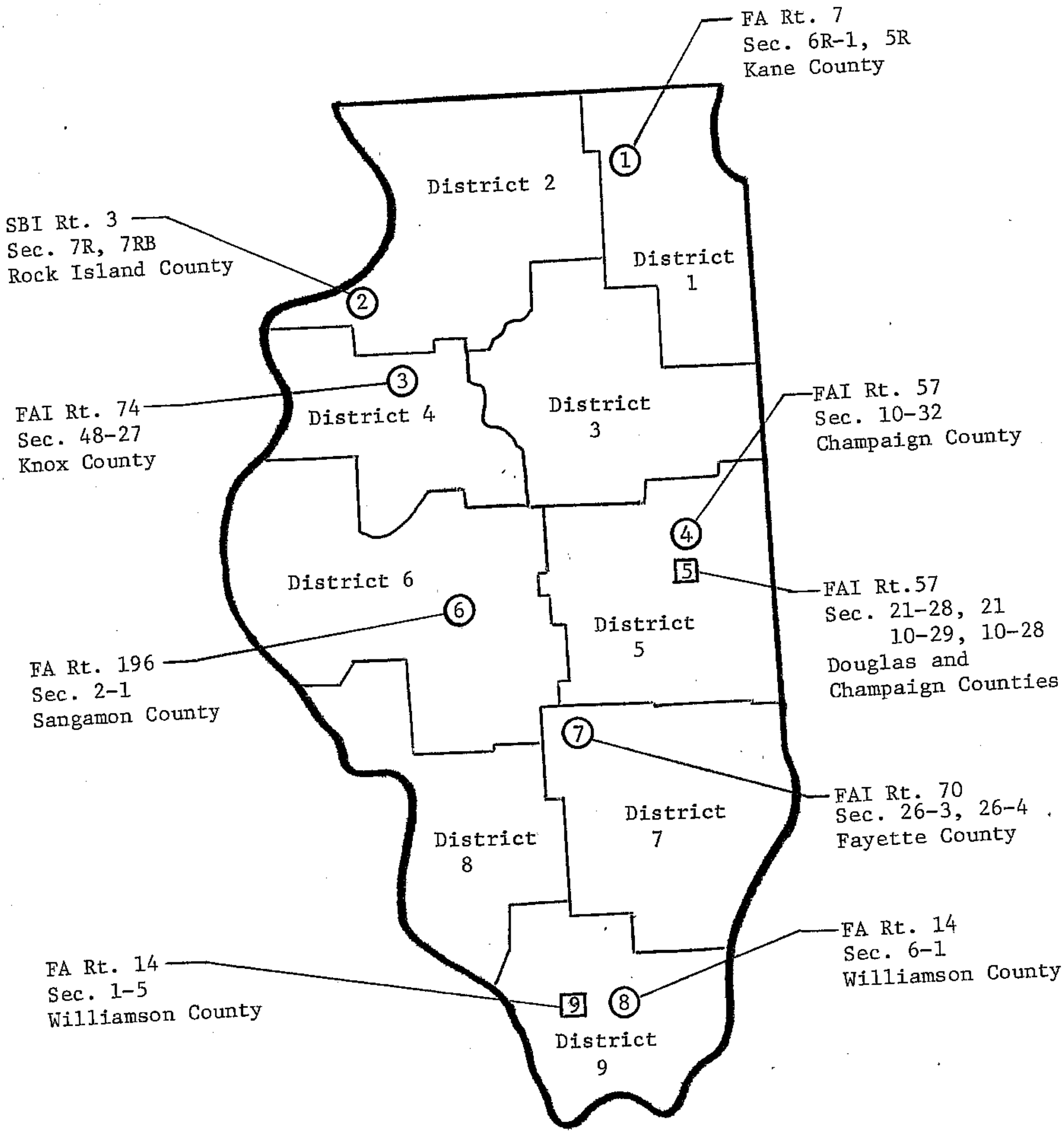
Geographic Location

The geographical location of each project is shown in Figure 1, and a listing of nine projects with corresponding experimental features is given in Table 1.

The climate in Illinois is temperate, but extreme variations in temperature can be expected from day to day, from month to month, and from year to year. In July, the warmest month of the year, the mean monthly temperature varies from 74°F (23°C) in the northern part of the State to 80°F (27°C) in the southern part of the State. During January, the coldest month of the year, the mean monthly temperature for the northern part is 20°F (-6.7°C) as compared with 38°F (3.3°C) in the southern part. The average annual frost penetration varies from 30 in. (762 mm) at the northwest corner of the State to 10 in. (254 mm) in the southern part of the State. The highest average annual precipitation, which occurs in the southern part, is 45 in. (1143 mm) and the lowest average annual precipitation is 32 in. (813 mm), which occurs in the northeastern part.

Subgrade and Subbase

On most projects the samples for field classification were taken from the finished grade at intervals of not more than 300 ft (91.4 m) and at locations where



○ Experimental Projects - having Anchor Systems

□ Experimental Projects having Expansion Systems

Figure 1. Map showing the location of experimental terminal treatments.

TABLE 1

DESIGN FEATURES OF EXPERIMENTAL PROJECTS

Project No.	District	Year Built	CRC Slab Thickness (in.)	Reinforcement Type	1/ Details of Lug Anchor	2/ Detail of Expansion System	No. of Terminal Treatments
1	1	1964	7	Bars	4 @ 20 ft	-	1
2	2	1964	8	Fabric	4 @ 40 ft	-	6
3	4	1963-64	7	Bars	4 @ 20 ft	-	4
4	5	1963	7 8	Bars	5 @ 40 ft 5 @ 40 ft	- -	1 1
5	5	1970	7	Bars	-	Wide-flange Beam	6
6	6	1966	7 7 8 8	Fabric Bars Fabric Bars	3 @ 40 ft 4 @ 40 ft 3 @ 40 ft 4 @ 40 ft	- - - -	2 2 2 2
7	7	1963	8	Bars	4 @ 40 ft	-	2
8	9	1964-65	7	Fabric	3 @ 40 ft	-	5
9	9	1971	8	Bars	-	Wide-flange Beam	4

1/ Three 3/4-in. preformed bituminous fiber expansion joints (doweled) spaced at 50-ft centers between end of CRC pavement and standard pavement are provided. Five joints are provided at locations where end anchorage of CRC pavement is at a bridge approach pavement.

2/ At the CRC pavement side of the beam a 1½-in. expansion space filled with ethafoam is provided. A 1½-in. expansion joint is also provided in the jointed pavement at a distance of 30'-6" from the beam.

1 ft = 0.305 m

the roadbed soil changes in type. The main soil types found at each project site having lug anchors are summarized in Table 2.

The thickness of the subbase under experimental CRC pavement is 4 in. (102 mm) while that under the conventional 10-in. (254-mm) PCC pavement is 6 in. (152 mm). Dense-grade granular material was used for the pavements containing lug anchorage systems while bituminous aggregate mix was used for the pavements containing the wide-flange beam terminal joint. Gravel was used in Districts 1, 4, 6 and 7 (Projects 1, 3, 6 and 7) while crushed stone was used in Districts 2, 5 and 9 (Projects 2, 4 and 8), and bituminous aggregate mix was used in Districts 5 and 9 (Projects 5 and 9).

Construction

Typical details of the four-lug anchor system are presented in Figure 2. The main function of the lug anchorage system is to restrict the movement by transferring the pavement movement forces to the soil mass through the passive and shear resistance of the subsoil. Therefore, lugs were cast directly into trenches in the embankment without forms to achieve maximum resistance. These trenches were 2 ft (0.61 m) wide, 4 ft (1.22 m) deep and extended across the full width of the pavement. The lug reinforcing steel assembly was fabricated, lowered into the trench, held at the proper location with wooden 2 x 4's while the concrete was poured into the trench. The concrete was cured for a period of at least 7 days by covering with burlap and maintaining a moist condition. The ends of the reinforcement protruding from the concrete were later bent and tied to the mainline steel as shown in Figure 3.

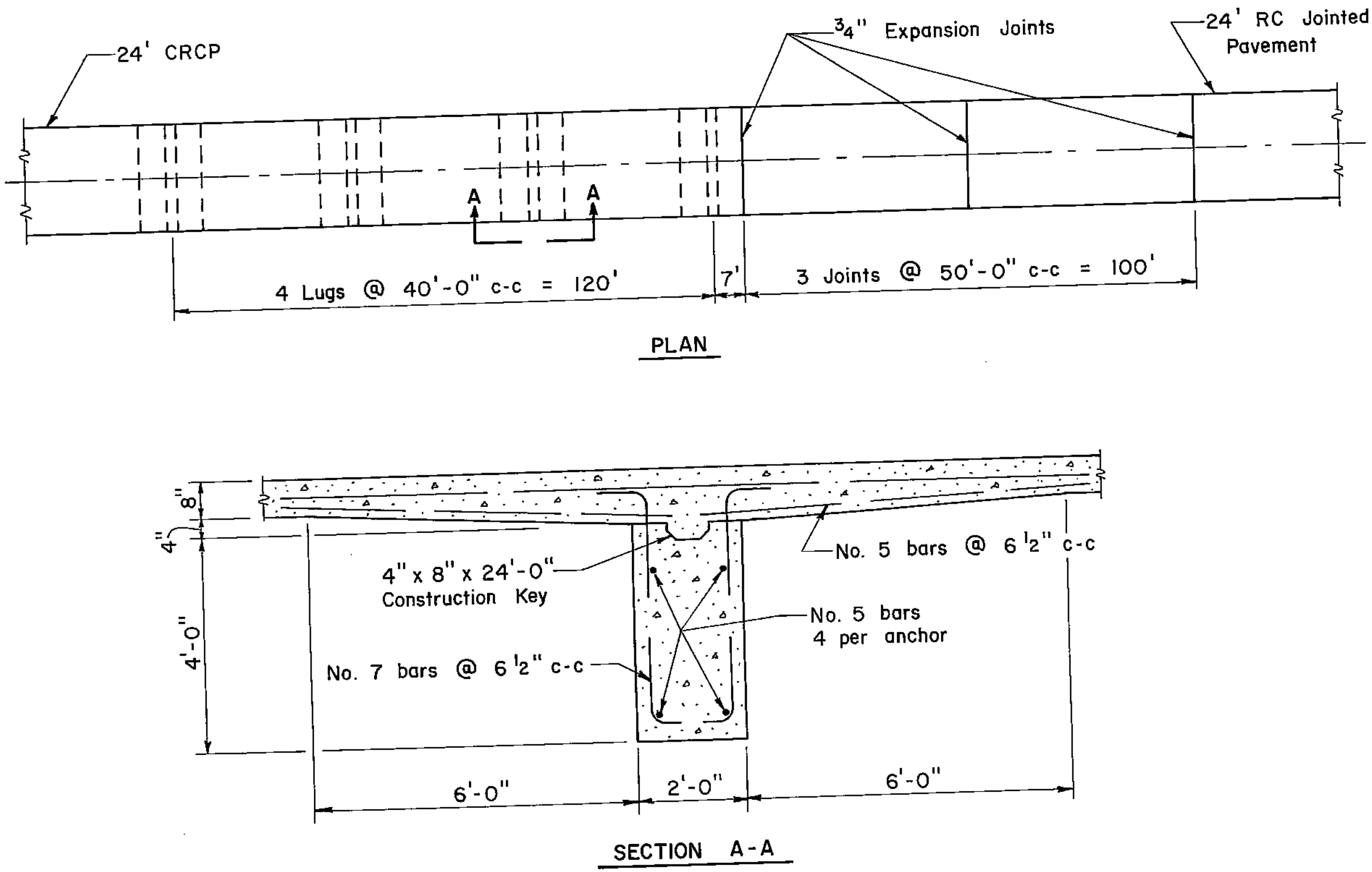
The wide-flange beam terminal joint provides for expansion and contraction of the CRC pavement. Typical details of this joint are presented in Figures 4 and 5. The wide-flange beam was cast into a reinforced "sleeper slab" which supports the ends of the abutting pavements. Provision for expansion was provided

TABLE 2

CLASSIFICATION OF SOILS
(AASHO Classification)

Project No.	Depth Below Subgrade (ft)	Soil Classification (Percent of Samples)				
		A-1	A-2	A-4	A-6	A-7
1	0-5	-	4	24	53	19
2	0-5	8	31	61	-	-
3	0-5	-	-	12	60	28
4	0-3	-	-	-	30	70
6	0-5	-	-	22	61	17
7	0-5	-	-	20	45	35
8	0-5	-	-	25	64	12

1 ft = 0.305 m



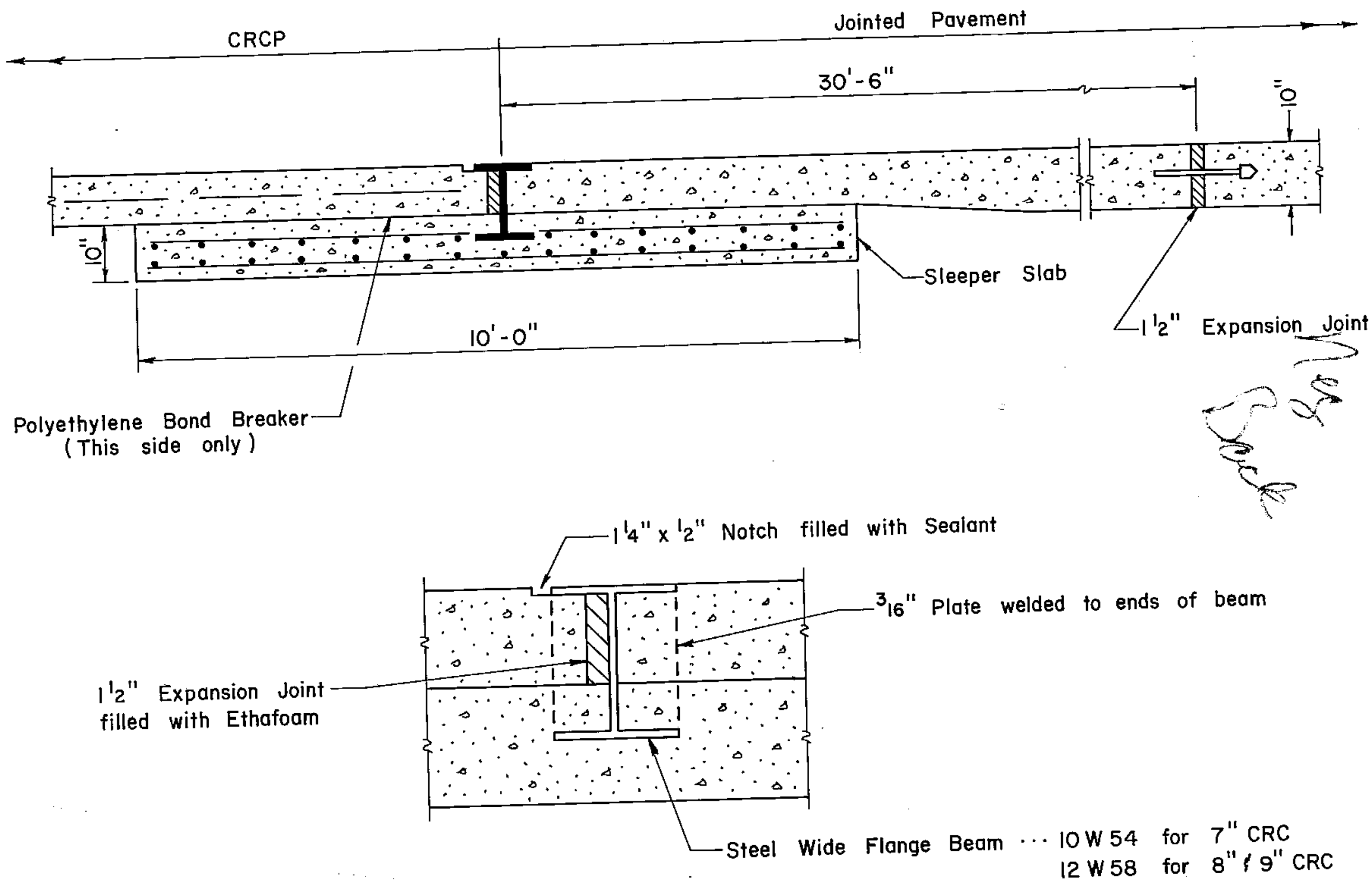
1 in. = 25.4 mm
1 ft = 0.305 m

Figure 2. Design Of Four-Lug Anchor System.

10

Neg
Back

Neg Back



1 in. = 25.4 mm
1 ft = 0.305 m

Figure 4. Details Of A Terminal Joint System.

by placing a 1 1/2-in. (38-mm) layer of ethafoam between the web of the beam and the end of the CRC pavement. In addition, one 1 1/2-in. (38-mm) conventional expansion joint was provided in the jointed pavement at a distance of 30' -6" (9.3 m) from the beam joint. To minimize corrosion of the beam, provisions for drainage of the ethafoam expansion material were made by drilling two 1/2-in. (13-mm) dia. holes in steel plates welded to the ends of the beam. The use of forms below the subgrade was strictly prohibited. Suitable seating devices were installed for the support of the steel beam during construction of the concrete pad. The concrete pad was constructed in a single continuous pour for the entire transverse width, and was properly cured prior to paving. The side of the pad, which supports the CRC pavement, was covered with polyethylene to break the bond between the pad and the CRC slab.

METHOD OF TAKING DATA

To measure the anchorage movement, reference monuments were installed near the right-of-way lines on opposite sides of the pavement. Reference plugs were installed eight inches (203 mm) in from both edges of the pavement. These monuments and plugs were installed as nearly as possible on a line perpendicular to the centerline of the 24-ft. (7.3-m) pavement. Readings were taken with the aid of a transit and a graduated steel rule. The initial location of the plugs was determined and recorded. Subsequent displacement of the anchorage was determined by measurements of offsets from the reference line. Readings were made bimonthly through the first winter and summer seasons following construction on some of the projects, but a minimum of one winter and one summer reading was taken on all projects.

Reference points for the wide-flange beam terminal joints constructed in 1970 consisted of plugs in the beam itself for measuring the beam movement, and plugs in the CRC pavement, approximately 10 in. (254 mm) from the plugs in the beam, to measure the movement of the free end of the CRC slab. Measurements were made relative to reference monuments installed near the right-of-way lines. Also, the change in the distance between the plugs of the beams and the plugs of the CRC was obtained with a Whittemore Gage.

Also, on most of the projects, condition surveys were conducted on the 300 ft (91.4 m) directly preceding the lug anchorages or terminal joints. These readings were made once a year on some projects and mid-summer and mid-winter on others.

FIELD DATA

Anchor System

Measurements of the end lug positions at each experimental location as recorded during mid-winter and mid-summer are presented in Table 3. This information is also shown graphically in Figures 6 through 13. It was not always possible to make measurements under extreme environmental conditions; therefore, the recorded readings are not necessarily the maximum for the yearly cycle. Because the initial measurements at each project were not made immediately after the concrete had set, but at a variable slab age, the changes shown are not necessarily the total change. The data are not corrected for unmeasured variations such as subbase friction, moisture content of slab and subbase, temperature of concrete and air during paving, season of pavement construction, and the type of soil in the embankments. Most of these factors could not be measured and evaluated even on supposedly similar sections.

During the planning stage of this study, it was decided that movements from winter to summer of approximately 3/4 in. (19 mm) or less would probably indicate satisfactory performance. The data in Table 3 were used to compute the average annual winter-to-summer movements for each District. Some data points which

TABLE 3

SUMMARY OF LUG MOVEMENT READINGS (INCHES)
(End Lug Only)

Dist.-Site No.	(Slab Thick., in.-Reinf. Type-Cover Depth, in.)	Lug Arrange.	1965		1966		1967		1968		1969	
			Mid-Winter	Mid-Summer	Mid-Winter	Mid-Summer	Mid-Winter	Mid-Summer	Mid-Winter	Mid-Summer	Mid-Winter	Mid-Summer
1-1	7-B-2	4 @ 20'	.250 C	.219 C	.313 C	.062 C	.500 C			.062 E	.390 C	.328 E
2-1	8-F-4	4 @ 40'	.250 C	.531 E	.094 E	.906 E	.125 C	.250 E	.562 C	.062 E	.062 C	.125 E
2-2	8-F-4		.250 E	.188 E	.025 C	.188 E	.250 C	.250 C	.250 C	.000	.250 E	.000
2-3	8-F-3		.172 E	.094 C	.343 C	.125 C	.094 C	.125 C	.000	.000	.000	.000
2-4	8-F-2		.266 E	.406 E	.234 C	.531 E	.031 E	.688 E	.000	.688 E	.062 E	.562 E
2-5	8-F-2		.063 E	.531 E	.063 E	.844 E	.438 E	1.188 E	.438 E	1.062 E	Overlayed	
2-6	8-F-2		.547 C	.344 E	.063 C	.219 C	.812 C	.438 C	.063 C	.375 C	.688 C	.250 C
4-1	7-B-2	4 @ 40	.075 E	.000				.000	.042 E			.040 E
4-2	7-B-3.5		.000	.000				.010 E	.012 C			.070 E
4-3	7-F-3.5		.000	.000				.000	Unusable		Unusable	
4-4	7-F-3.5		.005 E	.015 C				.040 E	.015 E			.050 E
5-1	8-B-4	5 @ 40'		.106 C	.325 E	.142 C	.460 C	.260 C	.525 C	.318 C	.638 C	.263 C
5-2	7-B-3.5			.288 C	.375 E	.156 C	.440 C	.026 C	.394 C	.038 E	.100 C	.075 E
6-1	8-B-2	4 @ 40'					.070 C	.740 E	.090 C	.430 E	.030 C	
6-2	8-F-4	3 @ 40'					.290 C	.520 E	.220 C	.930 E	.040 C	
6-3	7-8-3.5	4 @ 40'					.150 C	.630 E	.170 C	.260 E	.240 C	
6-4	7-F-2	3 @ 40'					.380 C	.350 E	.210 C	.540 E	.050 C	
7-1	8-B-2	4 @ 40'		.210 E	.190 C	.020 E	.140 E	.470 E	.230 E	.540 E	.250 E	.760 E
7-2	8-B-4			.620 E	.160 E	.570 E	.290 E	.560 E	.140E	.540 E	.200 E	.770 E
9-1	7-F-2	3 @ 40'	.000	.020 E	.050 E	.340 E	.090 E	.230 E		.210 E	.110 E	.130 E
9-2	7-F-2		.000	.020 E	.170 C	.300 C	.220 E	.620 E		.830 E	.460 E	.960 E
9-3	7-F-2		.000	.040 E	.210 E	.380 E	.280 E	.780 E		1.040 E	.680 E	1.420 E
9-4	7-F-3.5			.000	.130 C	.410 E	.170 E	.570 E		.910 E	.700 E	1.180 E
9-5	7-F-3.5			.000	.060 E	.360 E	.180 C	.680 E		.370 E	.170 C	.350 E

Note: C denotes contraction from initial reference.
E denotes expansion from initial reference.

1 in. = 25.4 mm
1 ft = 0.305 m

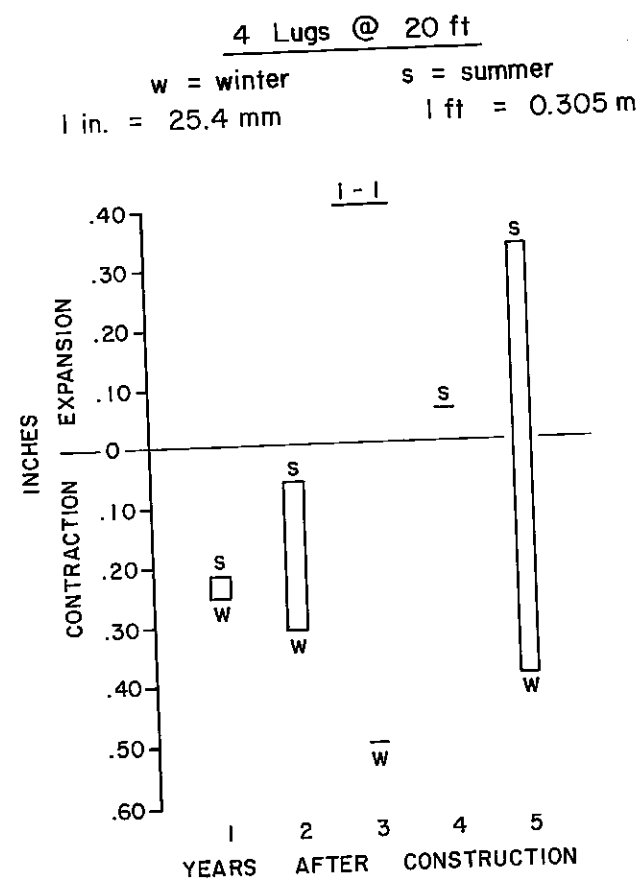


Figure 6. Annual And Progressive Movements Of End Anchors In District 1.

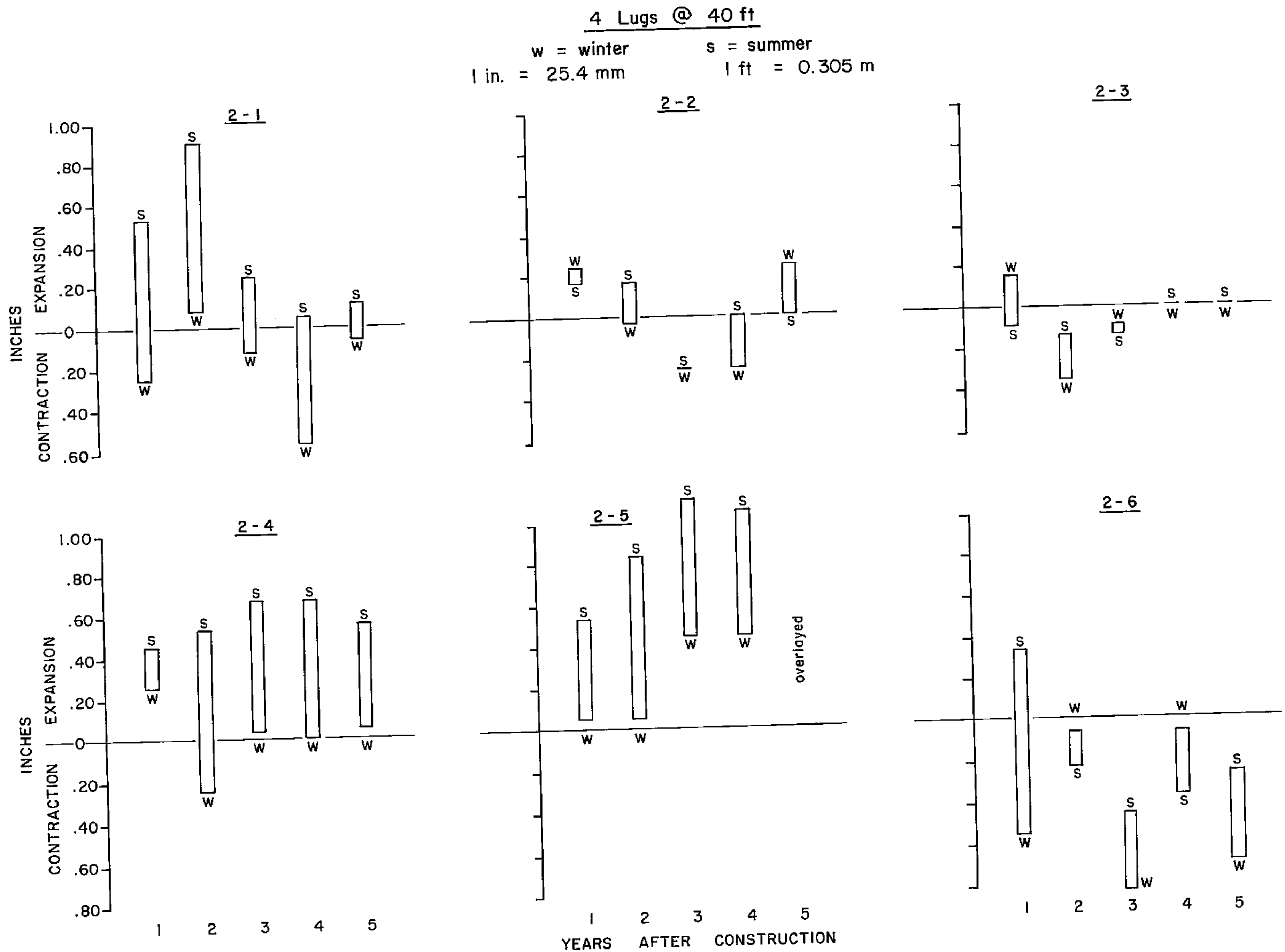


Figure 7. Annual And Progressive Movements Of End Anchors In District 2.

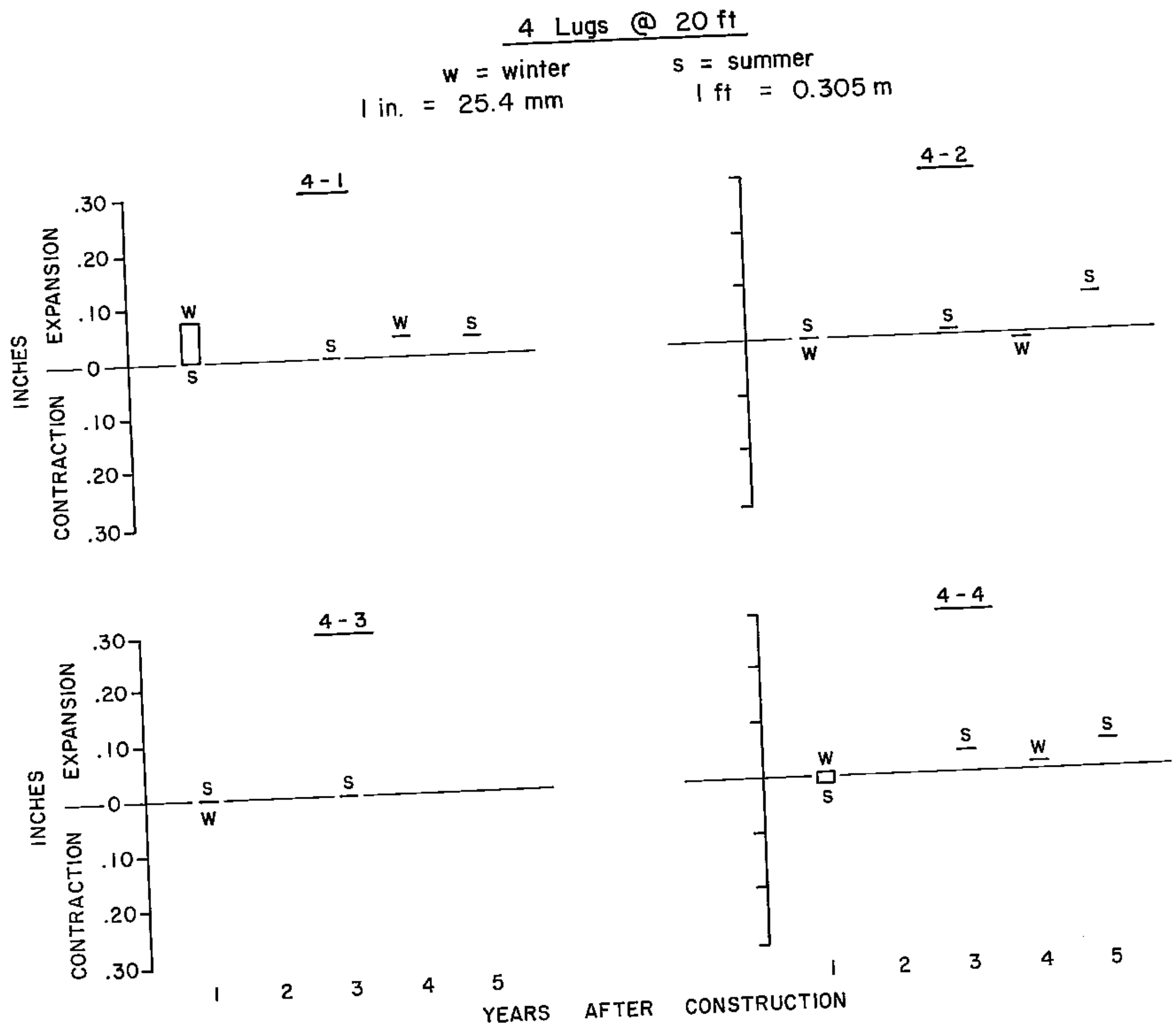


Figure 8. Annual And Progressive Movements Of End Anchors In District 4.

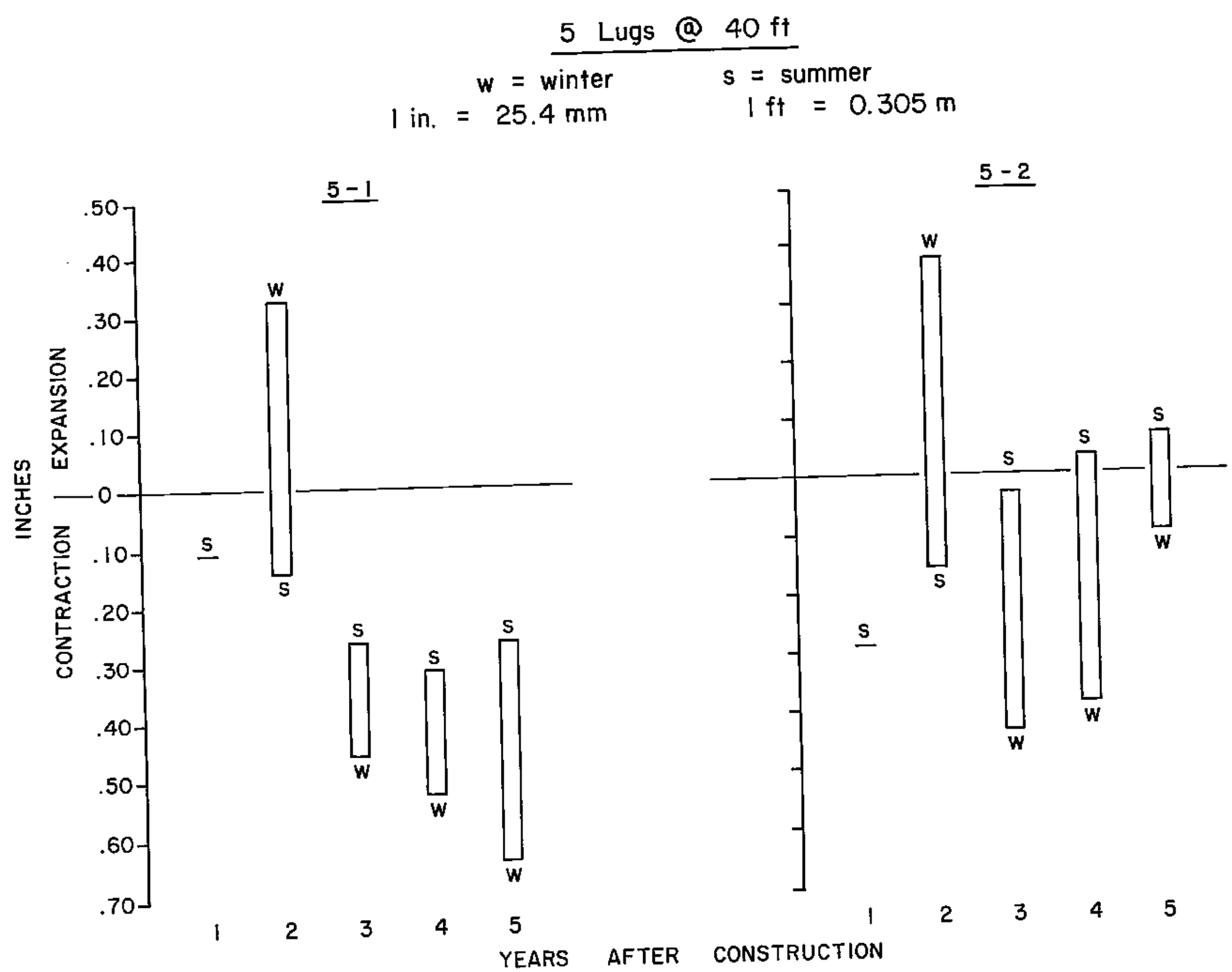


Figure 9. Annual And Progressive Movements Of End Anchors In District 5.

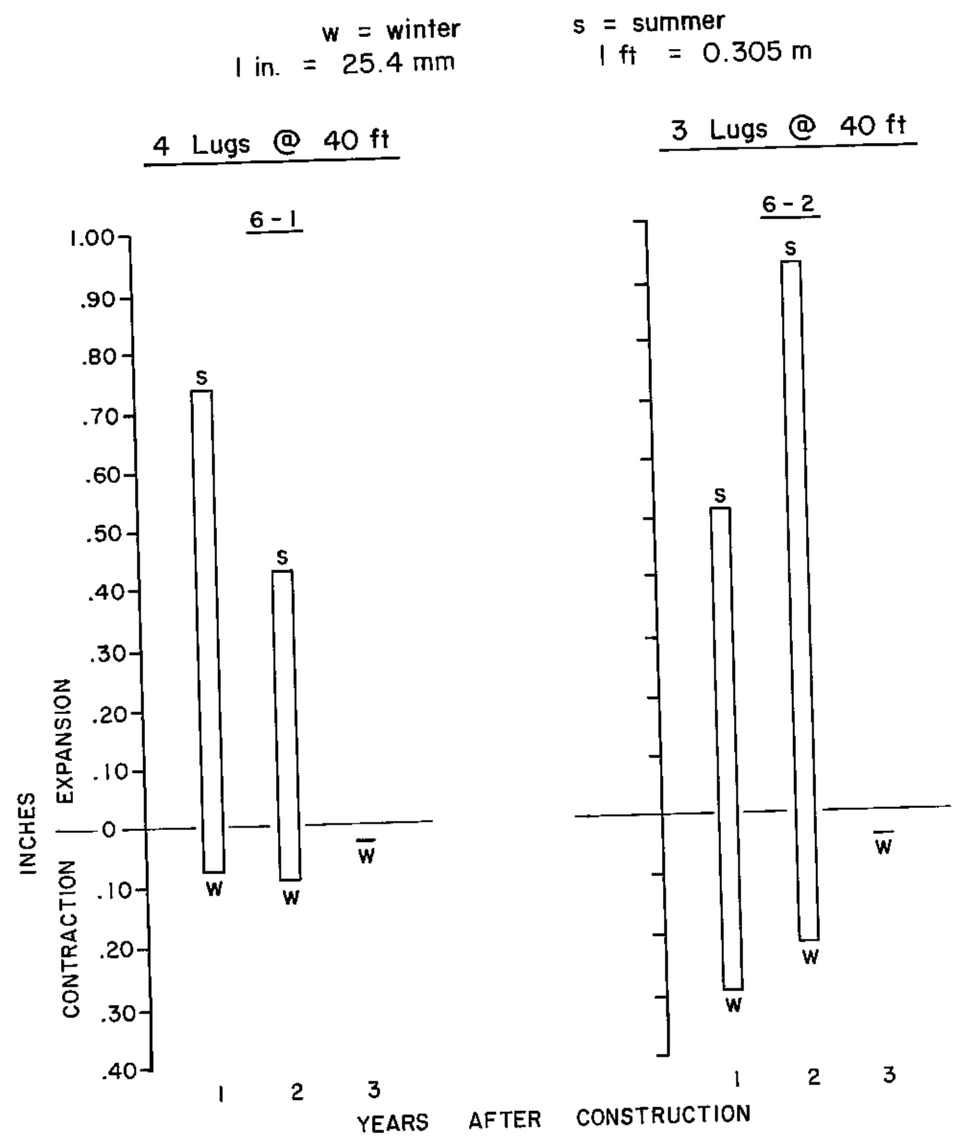


Figure 10. Annual And Progressive Movements Of End Anchors In District 6.

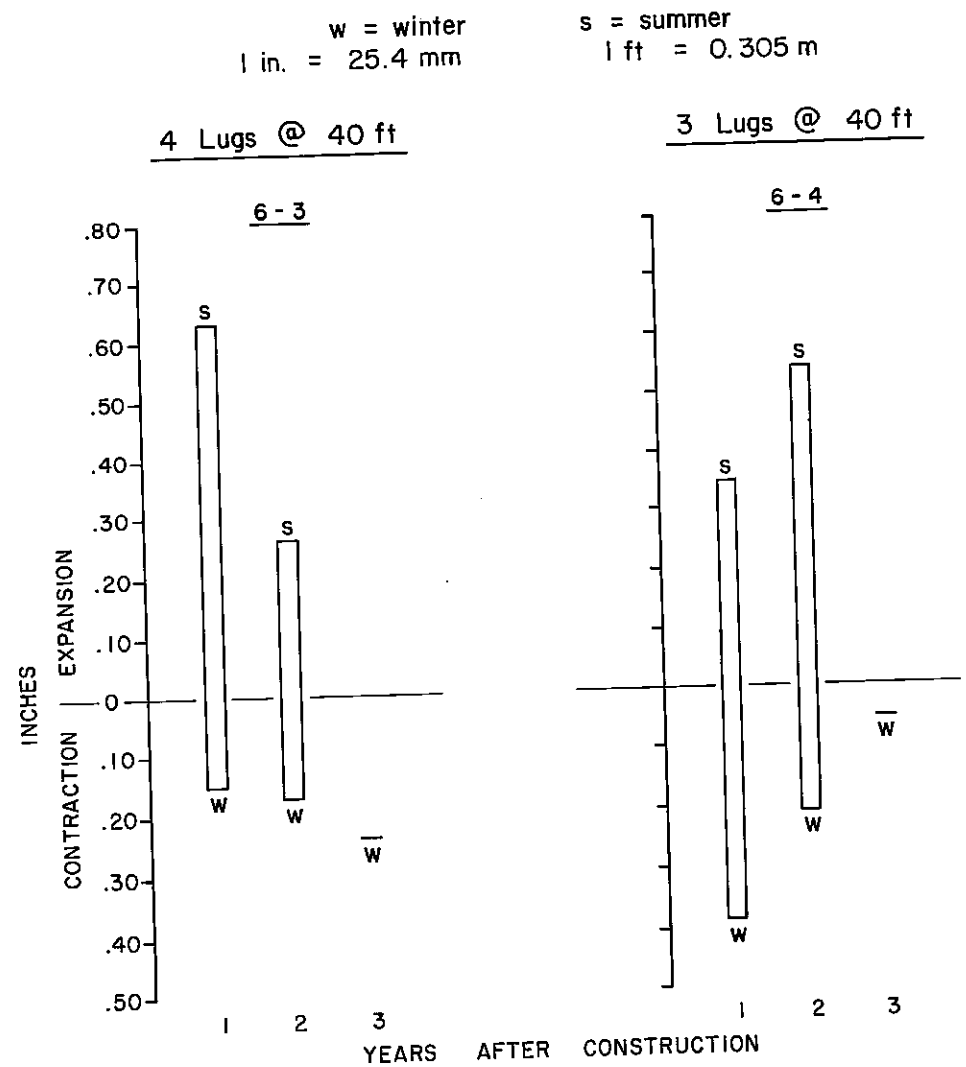


Figure 11. Annual And Progressive Movements Of End Anchors In District 6.

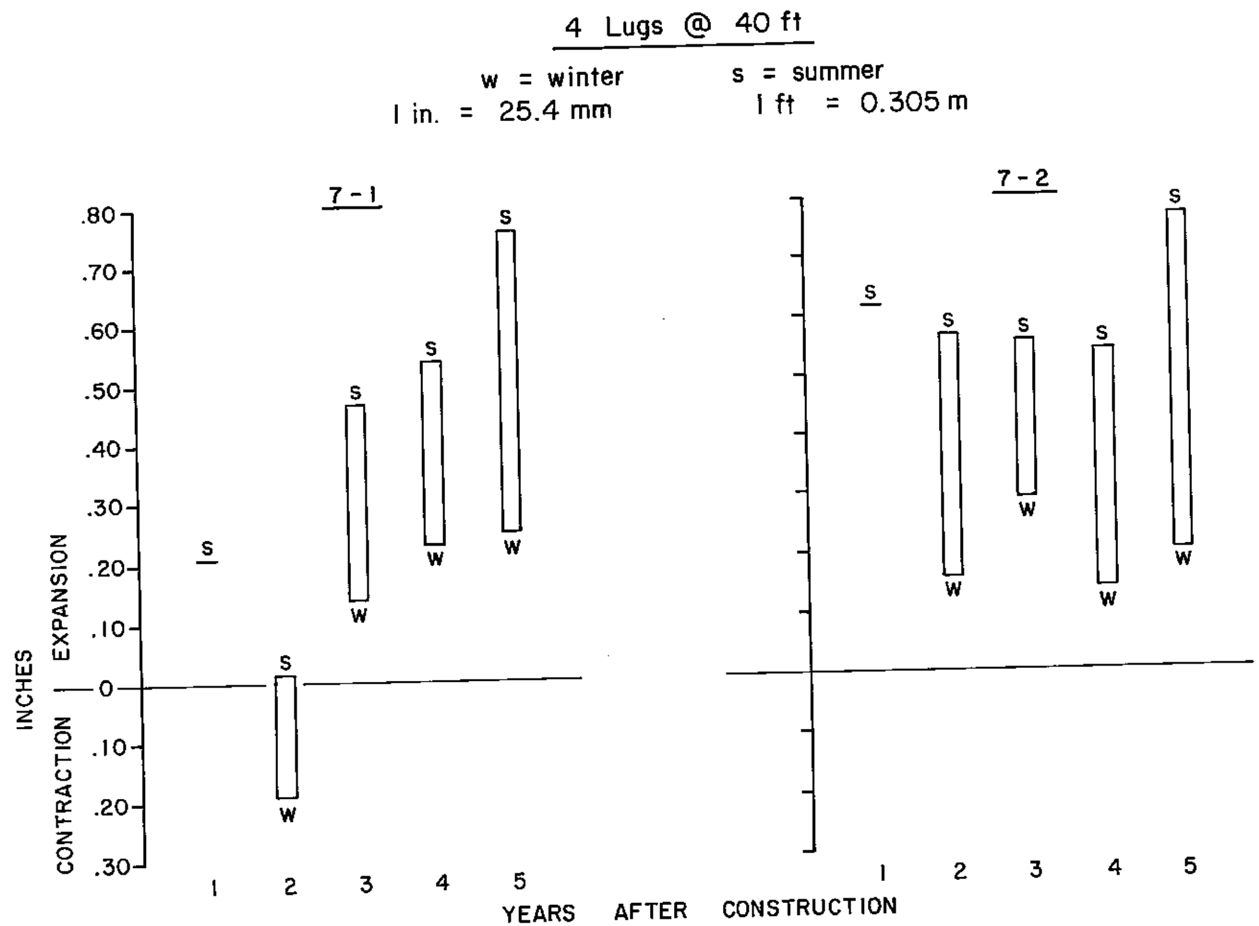


Figure 12. Annual And Progressive Movements Of End Anchors In District 7.

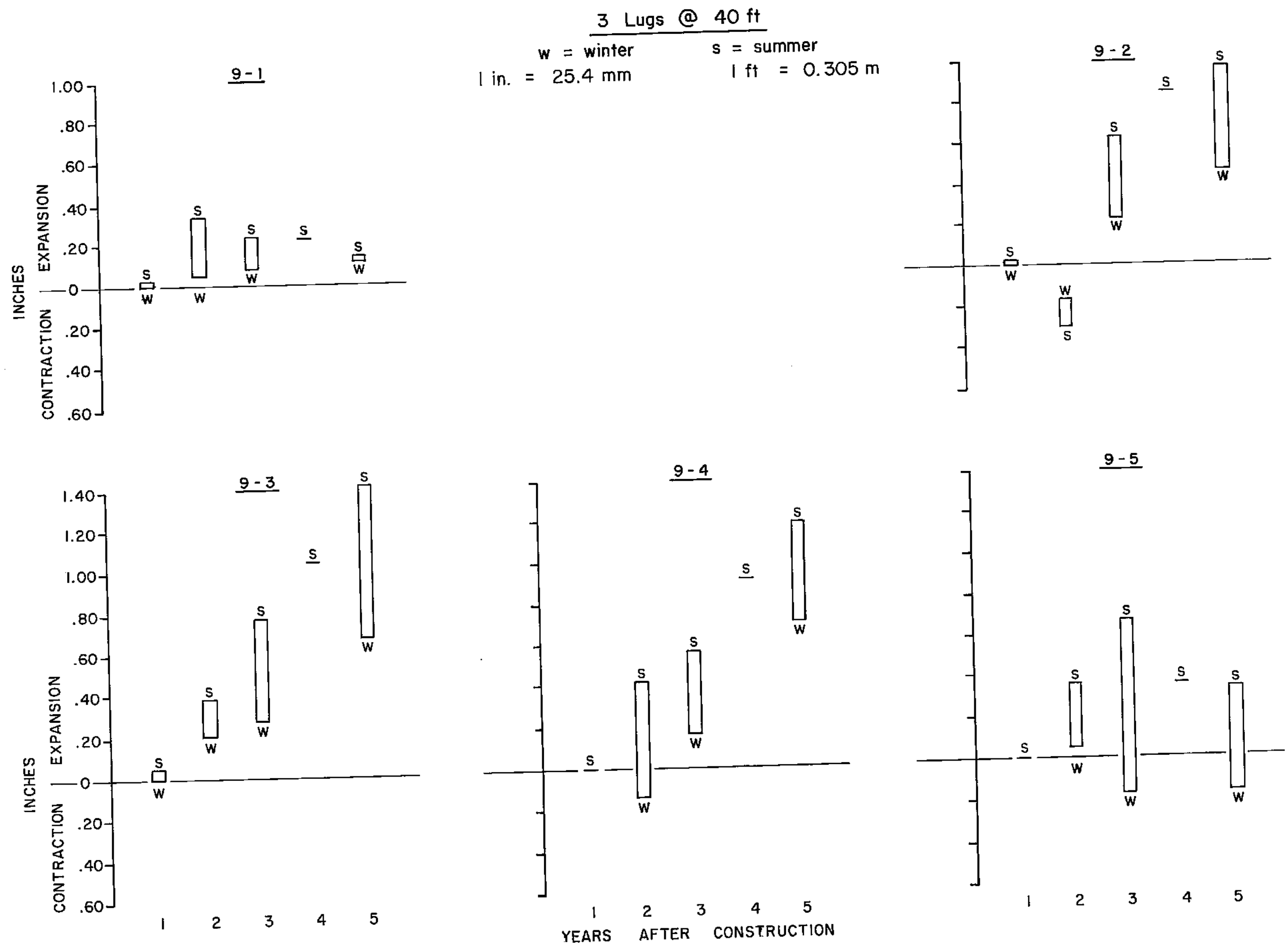


Figure 13. Annual And Progressive Movements Of End Anchors In District 9.

appear to be in error, such as the readings indicating that the lugs contracted from winter to summer were not used in the analysis. The results of the analysis are shown in Table 4.

Table 4 indicates a general trend for the average annual winter-to-summer lug movements to decrease from the northern to the southern part of the state. The average movements in Districts 5 and 6 in the central part of the state do not follow this trend; however, only limited data are available from these Districts. The combined average winter-to-summer movements in Districts 1 and 2 are 22 percent greater than the average movements in Districts 7 and 9. This variation may possibly be attributed to the difference in mean monthly temperatures for January and July in the northern and southern parts of the state. The January to July difference between monthly temperatures in northern Illinois is 54°F (5.6° C), which is 22 percent greater than the corresponding 42° F (5.6° C) mean monthly temperature variation in southern Illinois.

Another factor which may have influenced the magnitude of the lug movements is the soil type in which the lugs were constructed (Table 2). In District 2 the soil consisted of silty sand with some gravel, while in Districts 7 and 9 the soil was predominantly clay.

Assuming a normal distribution of the limited available data, it is possible to infer the probability of the lug movements exceeing 3/4 in. (19 mm) from winter-to-summer. The final column of Table 4 shows the percentage of lug locations in each District which would be expected to exceed 3/4-in. (19-mm) expansion from winter to summer. If District 6 is excluded because of very limited data, the highest percentage of winter-to-summer expansions exceeding 3/4 in. (19 mm) would occur in the northern part of the state, where the highest temperature variations occur.

TABLE 4

WINTER-TO-SUMMER LUG MOVEMENTS

District	Winter Lug Arrangement	Number of Locations	Years of Valid Data	Average Annual W-S Movement (inches)	Range in Annual W-S Movements (inches)	Percent Expected To Exceed 3/4 in.
1	4 @ 20'	1	3	.33	.031 - .718	12
2	4 @ 40'	6	5	.47	0 - .891	17
4	4 @ 20'	4	-	Insufficient Data		
5	5 @ 40'	2	3	.30	.175 - .414	0
6	3 @ 40' 4 @ 40'	2 2	2 2	.75	.430 -1.150	50
7	4 @ 40'	2	4	.38	.210 - .570	0
9	3 @ 40'	5	4	.35	.020 - .860	6

1 in. = 25.4 mm
1 ft = 0.305 m

Another criterion on which to base an assessment of the satisfactory performance of lug anchor systems is the amount of "growth" occurring at the pavement ends. Annual growth may be defined as the permanent displacement of the end of the pavement after undergoing a complete annual cyclical movement of expansion and contraction. One means of determining the amount of growth occurring at the experimental sections is to compute the difference between average annual winter-to-summer expansion and average annual summer to winter contraction. These differences are shown in Table 5, which indicates that the amount of growth varies from a growth of about .01 in. (0.25 mm) per year in northern Illinois to a growth of .07 in. (1.78 mm) per year in southern Illinois. These results indicate that the least growth occurs in the northern part of the state where the largest annual average movements occur. Conversely, the most growth appears to occur in the southern part of the state where smaller average annual movements occur. The reason for this phenomenon is not known at this time, although several factors such as differences in embankment soil, differences in environmental factors, and differences in number of lugs may contribute to the variation in growth rate.

In Table 6 three relationships, which are of special significance, are shown. The first is the relationship between crack development within an anchor area and CRC pavement adjacent to it, the second is between crack development and age, and the third is between crack development and the depth of reinforcement. With regard to the crack development within the anchor area and CRC pavement adjacent to the anchor area, it can be derived from Table 6 that spacing of the cracks is greater for the anchor area than for the CRC pavement adjacent to it. Performance has indicated that the structural capacity of the CRC pavement has not been impaired due to this difference of crack development.

A definite relationship between crack development and age can be established from Table 6. For most of the test pavements, the number of cracks has increased

TABLE 5

GROWTH OF PAVEMENT ENDS

District	Lug Arrangement	Number of Locations	Years of Valid Data	Average Annual W-S Movements (inches)	Average Annual S-W Movements (inches)	Difference (Tendency for Growth) in./Year
1	4 @ 20'	1	3	.33	.33	0
2	4 @ 40'	6	5	.47	.46	.01
4	4 @ 20'	4	–	Insufficient Data		
5	5 @ 40'	2	3	.30	.28	.02
6	3 @ 40'	2	2	.75	.68	.07
	4 @ 40'	2	2			
7	4 @ 40'	2	4	.38	.35	.03
9	3 @ 40'	5	4	.35	.28	.07

1 in. = 25.4 mm
1 ft = 0.305 m

TABLE 6

TRANSVERSE CRACKING AT END ANCHORAGE

District-Site No.	*	Date	Transverse Cracking: Lug Area: Length (ft)	Lug Area: No. of Cracks	300 ft CRC Next to Lug Area: No. of Cracks	300 ft CRC Next to Lug Area: Crack Interval (ft)
1-1	7B2	1964	74 (4 @ 20 ft)	6	56	5.4
		1966		7	93	3.2
		1968		9	109	2.8
2-2	8F4	1964	134 (4 @ 40 ft)	3	22	13.6
		1966		7	31	9.7
		1968		21	45	6.7
2-3	8F3	1964	134	2	26	11.5
		1966		6	31	9.7
		1968		24	40	7.5
2-4	8F2	1964	134	2	36	8.2
		1966		2	61	4.9
		1968		2	72	4.2
2-5	8F2	1964	134	1	30	10.0
		1966		7	78	3.8
		1968		7	95	3.2
2-6	8F2	1964	134	0	4	75.0
		1966		2	27	10.1
		1968		2	35	8.6
4-1	7B2	1964	74 (4 @ 20 ft)	2	12	25.0
		1965		3	52	5.8
		1969		8	85	3.5
4-2	7B3.5	1964	74	1	41	7.3
		1965		4	44	6.8
		1969		6	55	5.4
4-3	7F3.5	1964	74	3	31	9.7
		1965		3	41	7.3
		1969		5	57	5.3
4-4	7F3.5	1964	74 (4 @ 20 ft)	1	21	14.3
		1965		1	41	7.3
		1969		3	45	6.7

TABLE 6. (Continued)

TRANSVERSE CRACKING AT END ANCHORAGE

District-Site No.	*	Date	Transverse Cracking: Lug Area: Length (ft)	Transverse Cracking: Lug Area: No. of Cracks	Transverse Cracking: 300 ft CRC Next to Lug Area: No. of Cracks	Transverse Cracking: 300 ft CRC Next to Lug Area: Crack Interval (ft)
5-1	8B4	1963	174 (5 @ 40 ft)	4	22	13.6
		1965		10	28	10.7
		1967		11	30	10.0
		1969		12	30	10.0
5-2	7B3.5	1963	174	7	25	12.0
		1965		13	30	10.0
		1967		16	31	9.7
		1968		18	31	9.7
6-1	8B2 1/	1966	134 (4 @ 40 ft)	0	0	-
		1967		9	28	4.1
		1968		15	35	3.3
		1969		17	41	2.8
		1970		18	41	2.8
		1971		25	47	2.5
		1972		29	50	2.3
		1974		37	52	2.2
6-2	8F4 2/	1966	94 (3 @ 40 ft)	0	5	31.0
		1967		6	18	8.6
		1968		8	19	8.2
		1969		8	19	8.2
		1970		9	21	7.4
		1971		9	23	6.7
		1972		25	29	5.3
		1974		32	31	5.0
6-3	7B3.5 1/	1966	134 (4 @ 40 ft)	0	3	39.0
		1967		14	18	6.4
		1968		19	18	6.4
		1969		19	18	6.4
		1970		22	18	6.4
		1971		24	18	6.4
		1972		24	18	6.4
		1974		24	19	6.1
6-4	7F2 2/	1966	94 (3 @ 40 ft)	0	1	-
		1967		1	25	6.2
		1968		5	35	4.4
		1969		5	35	4.4
		1970		5	35	4.4
		1971		7	41	3.8
		1972		28	47	3.3
		1974		47	84	1.8

TABLE 6. (Continued)

TRANSVERSE CRACKING AT END ANCHORAGE

District-Site No.	*	Date	Transverse Cracking: Lug Area: Length (ft)	Lug Area: No. of Cracks	300 ft CRC Next to Lug Area: No. of Cracks	300 ft CRC Next to Lug Area: Crack Interval (ft)
7-1	8B2	1963	134 (4 @ 40 ft)	0	17	17.6
		1965		23	117	2.6
		1967		24	136	2.2
		1969		43	145	2.1
7-2	8B4	1963	134	6	35	8.6
		1965		11	65	4.6
		1967		11	66	4.5
		1969		11	67	4.5
9-1	7F2	1965	94 (3 @ 40 ft)	0	12	25.0
		1966		0	15	20.0
		1968		0	29	10.3
		1970		0	40	7.5
9-2	7F2	1965	94	0	16	18.8
		1966		0	27	11.1
		1968		0	35	8.6
		1970		0	37	8.1
9-3	7F2	1965	94	0	13	23.1
		1966		0	23	13.0
		1968		1	28	10.6
		1970		1	30	10.0
9-4	7F3.5	1965	94	0	3	100.0
		1966		3	35	8.6
		1968		5	37	8.1
		1970		5	39	7.7
9-5	7F3.5	1965	94	0	3	100.0
		1966		0	31	9.7
		1968		1	32	9.4
		1970		1	33	9.1

* Slab Thickness (in.), Reinforcement Type, Cover Depth (in.).
1/ CRC next to lug area is 116 ft instead of 300 ft.
2/ CRC next to lug area is 155 ft instead of 300 ft.

1 in. = 25.4 mm
1 ft = 0.305 m

at a rather rapid rate during the early life of the pavement, after which the rate of increase becomes slower.

Another significant relationship shown in Table 6 is that slab thickness and type of steel reinforcement has little, if any, effect on transverse cracking. But the depth of steel reinforcement below the pavement surface has a major effect on transverse cracking. As expected, the transverse cracking increases as the reinforcement is placed nearer the pavement surface.

Terminal Joint System

Measurements of the movements of the pavement ends at wide-flange beam terminal joints in Districts 5 and 9 were made to determine the behavior of the joints. These measurements are included in Table 7. Movements of the wide-flange beams were also measured and are included in Table 8. Figures 14 and 15 compare the annual movements of the wide-flange beams and the free ends of the CRC slabs. As expected, the free end of the CRC slab moved toward the beam during the summer and away from the beam during the winter. The annual winter-to-summer movements of the free ends of the CRC slabs have been light to moderate, with the maximum annual movement at any joint not exceeding 3/4 in. (19 mm). The average winter-to-summer movements in District 5 were equal to 0.607 in. (15.4 mm), while in District 9 the average movements were equal to 0.559 in. (14.2 mm). A comparison of these average movements with the average winter-to-summer lug movements in Districts 5 and 9 (Table 4), indicates that roughly half as much movement occurred at the anchor lugs as occurred at the wide-flange beam joints.

The relative position of the bars in Figures 14 and 15 indicates the progressive changes in the locations of the free ends of the CRC slabs. There appears to be a slight tendency for the free ends to move permanently toward the web of the beam. At the time of construction, provision for progressive and annual expansion

TABLE 7

PAVEMENT MOVEMENTS AT TERMINAL JOINTS
(Inches)

District	Station	November 1970 Initial Reading	1971 Mid Winter	1971 Mid Summer	1972 Mid Winter	1972 Mid Summer	1973 Mid Winter	1973 Mid Summer
5	553 + 61 (NB)	0	.194 C	.295 E	.158 C	.330 E	.278 C	.393 E
	553 + 61 (SB)	0	.055 C	.395 E	.041 C	.486 E	.014 C	.571 E
	553 + 60 (NB)	0	.106 C	.364 E	.111 C	.424 E	.100 C	.462 E
	564 + 11 (SB)	0	.108 C	.619 E	.038 C	.694 E	.059 E	.791 E
	937 + 99 (NB)	0	.253 C	.477 E	.085 C	.573 E	.074 C	.627 E
	937 + 12 (SB)	0	-	.544 E	.026 C	.598 E	.108 E	.741 E
			1971 Initial Reading					
9	472 + 30	-		0	.273 C	.385 E	.110 E	.570 E
	538 + 08	-		0	.338 C	.058 E	.358 C	.293 E
	539 + 41.9	-		0	.421 C	.307 E	.192 C	.311 E
	605 + 94	-		0	.406 C	.252 E	.117 C	.303 E

1 in. = 25.4 mm

TABLE 8

WIDE-FLANGE BEAM MOVEMENTS AT TERMINAL JOINTS
(Inches)

District	Station	1971 Initial	1971 Mid Summer	1972 Mid Winter	1972 Mid Summer	1973 Mid Winter	1973 Mid Summer
5	553 + 61 (NB)	0	.031 C	.063 E	.031 E	.031 E	.031 E
	553 + 61 (SB)	0	.172 E	.031 C	.188 E	.109 E	.109 C
	563 + 60 (NB)	0	.000	.016 E	.110 C	.063 C	.203 C
	564 + 11 (SB)	0	.016 E	.031 E	.031 C	.047 E	.016 C
	937 + 99 (NB)	0	.000	.203 E	.000	.078 E	.156 E
	937 + 12 (SB)	0	.016 C	.094 E	.031 E	.015 E	.094 C
9	472 + 30	Broken Monument	-	-	-	-	-
	538 +08		0	.203 C	.172 E	.640 E	1.469 E
	539 + 41.9		0	.156 E	.574 E	.891 E	1.406 E
	605 + 94		0	.062 C	.174 C	.032 E	.250 C

1 in. = 25.4 mm

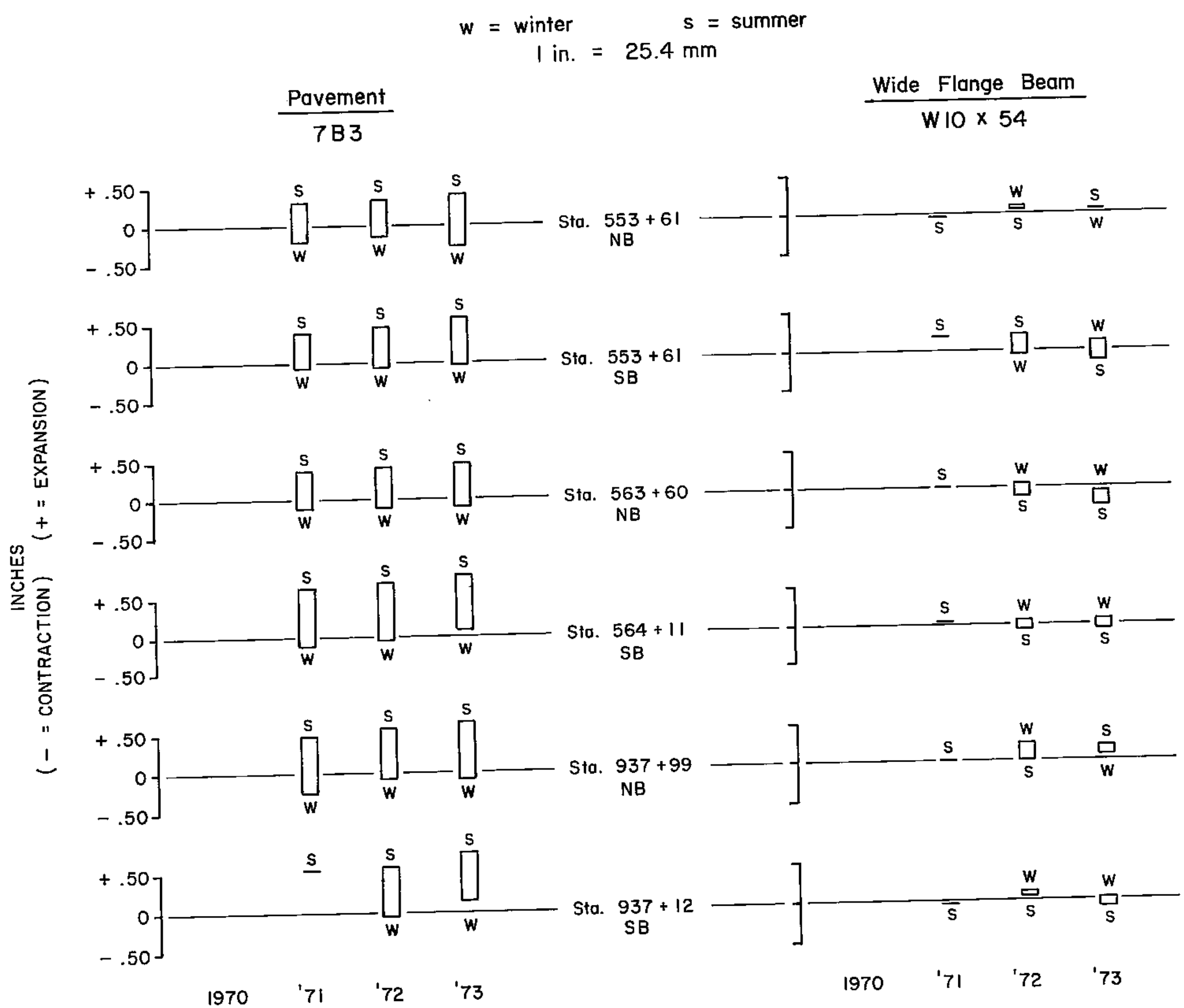


Figure 14. Pavement And Wide Flange Beam Movements In District 5.

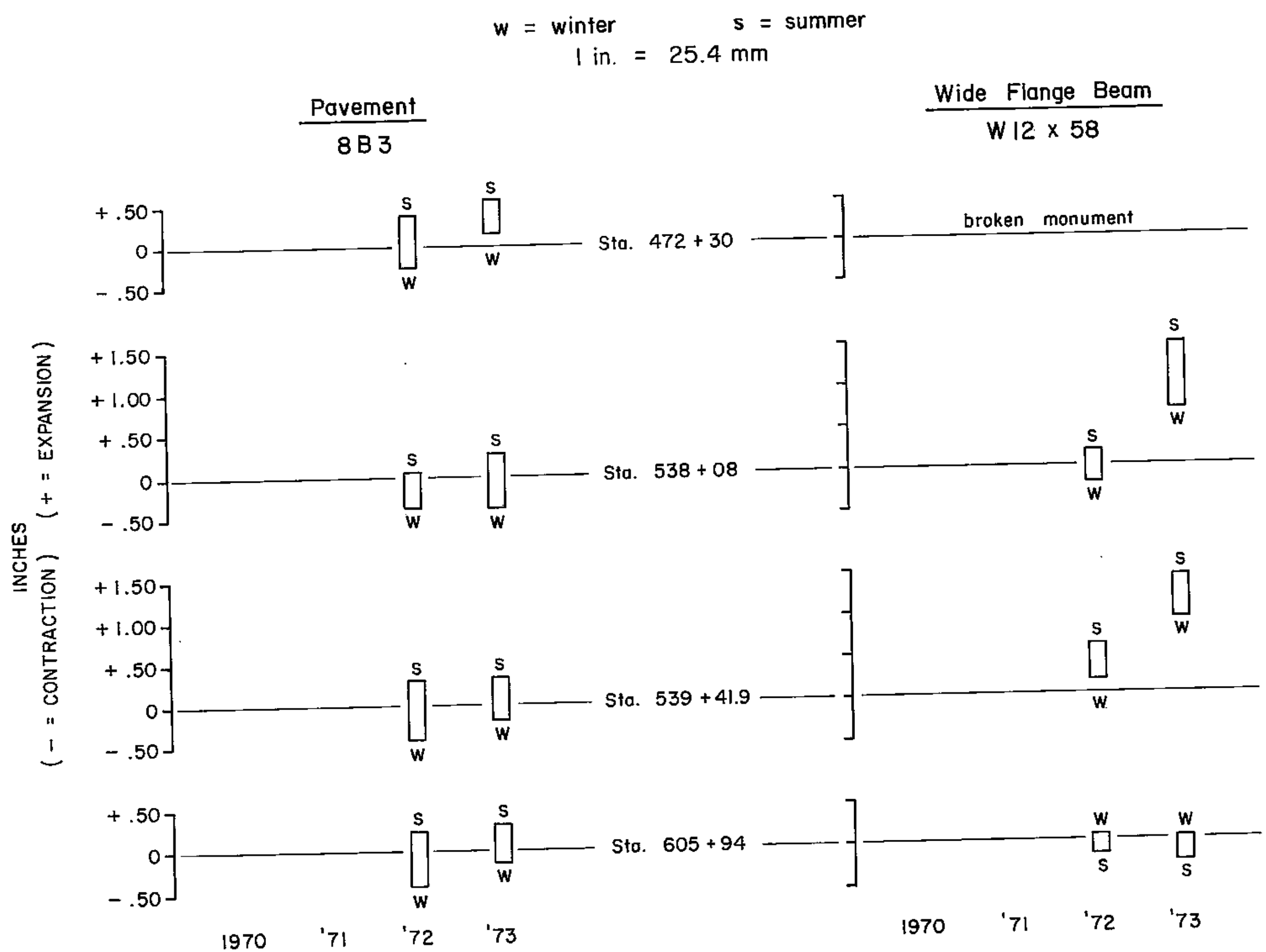


Figure 15. Pavement And Wide Flange Beam Movements In District 9.

was provided by placing a 1 1/2-in. (38-mm) layer of ethafoam between the web of the beam and the free end of the CRC slab.

The terminal joints were designed and constructed so that the beam should remain stationary. The data in Figure 14 indicate that the beams installed in District 5 did remain relatively stationary. Figure 15 indicates that two of the beams in District 9 moved considerably more than expected. The reference monuments for these beams are located near the right-of-way lines at a railroad crossing, and are much lower than the beams. Therefore, the establishment of the line-of-sight is more difficult, and measurements may be indicating erroneous results.

Table 9 contains a record of crack development within 300 ft (91.4 m) of the free ends of the pavements during the three years following construction. Except for a single crack forming near the edge of the underlying concrete pad about five feet from the free end in eight out of the ten cases, the length of uncracked pavement varied from 81 to 148 ft (24.7 to 45.1 m) from the free end. At these distances from the free ends, typical transverse cracking began and developed in a normal manner, with the cracks being relatively uniformly spaced and tight at the surface. Table 7 indicates that in the majority of cases, most of the cracks developed within the first year to 15 months after construction. The rate of increase in the number of cracks decreased substantially after the first 15 months. The single crack which developed near the ends of the underlying concrete pads is believed to be caused by a difference in pavement support provided by the subbase and the sleeper slab, causing a concentration of stress in the pavement at the edge of the sleeper slab when subjected to heavy traffic. These single cracks have not resulted in any problems after six to seven years.

In District 9, a construction joint is located within 29 to 59 ft (8.9 to 18.0 m) of each terminal joint. The pavement was constructed up to these construction joints during the late fall in 1970, while the terminal joints and remaining pavements were completed in the spring of 1971.

TABLE 9

TRANSVERSE CRACKING NEAR TERMINAL JOINTS

District	Station	Date Constructed	Number of Transverse Cracks Within 300 ft from Free End of Slab					* Distance From Free End To Beginning Of Typical Cracks (ft)
			8/71	1/72	6/72	1/73	7/73	
5	553 + 61 (NB)	9/70	33	34	34	34	34	110
	553 + 61 (SB)	11/70	6	20	20	22	23	118
	563 + 60 (NB)	9/70	29	34	34	35	35	98
	564 + 11 (SB)	10/70	18	19	19	20	20	111
	937 + 99 (NB)	10/70	11	18	21	24	24	135
	937 + 12 (SB)	10/70	13	19	20	21	21	110
9	472 + 30	-	12	28	32	38	40	102
	538 + 08	4/71	7	14	18	19	19	148
	539 + 41.9	5/71	16	19	23	24	24	142
	605 + 94	5/71	10	23	30	31	33	81

* Note: At eight out of the ten locations a single crack formed within five ft of the free end near the end of the sleeper slab.

1 ft = 0.305 m

The period of time over which data were collected at these sites is not sufficient to evaluate the effect, if any, of the cracks and construction joints on the performance of the terminal joints.

PERFORMANCE

Anchor System

In general, the performance of most anchor systems constructed since 1963 has been satisfactory. The anchor systems appear to have been effective in partially restraining the pavement movement and, in most cases, have provided a good low-maintenance riding surface. At one experimental five-lug anchor location and at a few scattered regularly constructed four-lug anchor locations, distress has developed in the form of a series of dips between lugs, large pavement deflections between lugs, circular tearing of the shoulder material in the vicinity of lugs, voids in the shoulder at the lugs and along the pavement shoulder joints between lugs, and reduction in the installed width of the 3/4-in. (19-mm) expansion joint adjacent to the lugs. In most cases the waviness of the pavement surface caused by the dips between lugs developed to the point where some form of corrective treatment was required about five years after construction. No sign of pavement structural distress was visible at these locations.

Profile measurements were made at three locations where dips have formed between lugs creating a roller coaster riding effect. The high points of the undulations range from 1/2 to 2 in. (13 to 51 mm) above grade, with the highest peak occuring near the end lug and the remaining peaks diminishing with distance from the end of the pavement. The peaks tend to occur at a distance of from two to four feet from the center of the lugs in the direction away from the end of the pavement. At some locations the elevations of the low points are at or near the original grade line, while at other locations the elevations of the valleys appear to be as much as 1 1/2 in. (38 mm) below grade. These conditions create a rough riding surface which is annoying and sometimes hazardous to motorists. The effect of the sequence of undulations appears to be particularly severe to truck traffic.

The offset of the peaks from the center of the lug indicates that the tops of the lugs may have moved toward the end of the pavement with respect to the bottom of the lugs, causing rotation of the pavement at the lug, and upward displacement of the pavement at some distance from the lug. Another possible explanation for the dips between lugs is differential settlement of the embankment between the top of the subgrade and the bottom of the lugs. It appears probable that the distress observed at some anchor systems is a combination of rotation and differential settlement.

In order to investigate the behavior of the rough anchor systems, excavations were made at some sites. A typical distressed anchor system before excavation is shown in Figure 16. A view of the same anchor system after an observation trench was excavated in the shoulder adjacent to the pavement is shown in Figure 17. The pavement is an 8-in. (203-mm) slab over a 4-in. (102-mm) CAM subbase, with a lug system consisting of four lugs spaced at 40-ft (12.2-m) centers. The pavement was constructed in the spring and early summer in 1966, and the observations presented here were made in the summer of 1971. Although the anchor system depicted is not one of the systems at which movements were measured as part of this study, the distressed area is similar to that which developed at one of the 23 lug systems included under the study.

The excavation revealed that voids about 6 to 12 in. (152 mm to 305 mm) in width had formed in the subbase adjacent to either side of each lug wall. These voids extended back along the lug walls at least five feet under the pavement. Relatively narrow voids were found to extend down along the interfaces of the lug walls and embankment. Between the lugs, a gap varying from 3/8 to 3/4 in. (9.5 to 19 mm) between the pavement and the subbase was observed. The pavement between lugs

40

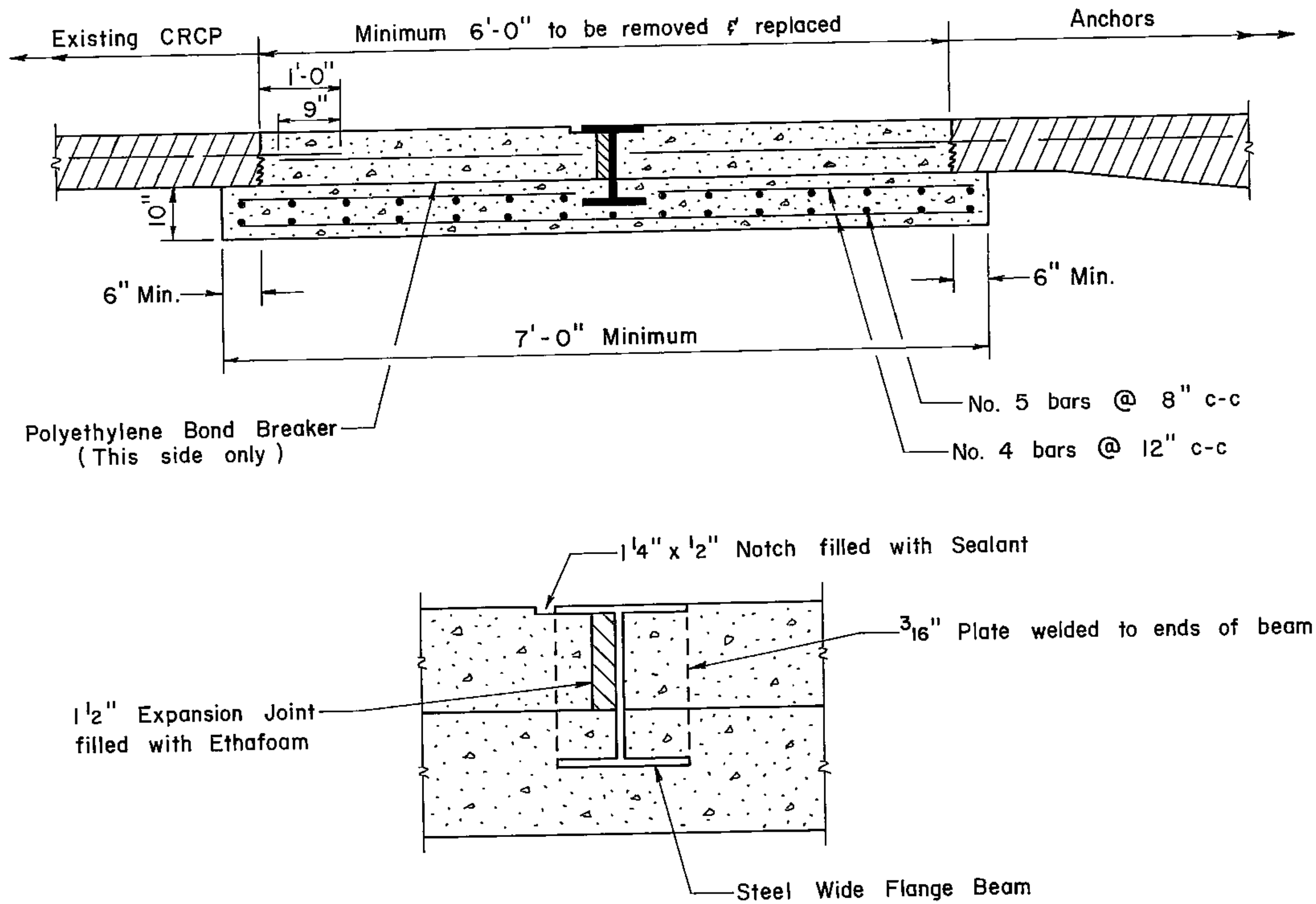
Neg

Back.

deflected under traffic loads due to a lack of any subgrade support. It was noted that the upper surface of the cement aggregate mixture (CAM) subbase in the void between the pavement and the subbase had developed signs of ravelling. The degree of distress was highest near the end lug and diminished with distance from the pavement end.

At that time the problem was thought to stem from forces exerted by the end of the conventional pavement on the end of the CRC pavement. An attempt to alleviate the problem was made by cutting a 4-in (102-mm) pressure relief joint in the conventional pavement near the construction joint. Ethafoam filler material was installed in the joint to prevent the intrusion of compressible material. The voids under the pavement were filled by mud-jacking with ag-lime portland cement slurry. To prevent pumping, perforated pipe underdrains outletting to the ditch were installed on both sides of the pavement along the entire anchor system. This corrective procedure was carried out five years ago and was temporarily successful in leveling the pavement; however, within three years the dips in the pavement between lugs formed again.

Another project manifesting similar distresses consists of a 7-in.(178 mm) slab on a 4-in. (102-mm) BAM subbase with an anchor system of four lugs on 40-ft (12.2-m) centers. In this case the end of the CRC pavement constructed in 1966 and 1967 abuts a bridge approach slab. By 1973, the waviness in the lug area and the thrust forces against the bridge approach slab had become severe. The cause of the problem was believed to be movement of the CRC pavement toward the anchored end and rotation of the anchors. In the fall of 1973 a 4-in. (102-mm) wide pressure relief joint was cut in the CRC pavement beyond the lug farthest from the bridge, and was filled with ethafoam expansion joint material. This joint was later modified by installing a wide-flange beam joint as shown in Figure 18.



1 in. = 25.4 mm
1 ft = 0.305 m

Figure 18. Wide - Flange Beam Joint For Repairing Distressed Lug Areas.

Based on the results of the two foregoing attempts to correct distressed lug areas, the following tentative procedures have been formulated and are now being evaluated in Illinois:

1. Cut a 4-in. (102-mm) wide joint in the CRC slab and fill it with ethafoam expansion joint material. Locate the joint a sufficient distance beyond the lugs to allow for ramping of any resurfacing that might later be necessary to correct the waviness and roughness at the lugs. The cutting should be done as early in the day as possible when the pavement is cool and thermal expansive forces are low. A cool cloudy day would be ideal.
2. Observe the area for a period of two to three months after cutting to see whether the roughness will decrease some on its own.
3. After the observation period, mud-jack the rough area to fill the voids under the pavement and to level, if possible, the rough area.
4. Provide drainage if required to eliminate pumping at any remaining voids.
5. If excessive roughness remains, overlay the rough anchor system with a minimum thickness of one inch bituminous concrete over the high spots.
6. The simple sawed expansion joint recommended in Item 1 may perform satisfactorily for many years. However, if distress develops in the 4-in. (102-mm) joint area, one of the expansion joints shown in Figure 18 and Figure 19 can be constructed.

The dowelled joint shown in Figure 19 is not known to have been used before in CRC pavement; however, this joint is designed to function similarly to the wide-flange beam joint, and has the advantage of being easier to construct and can be

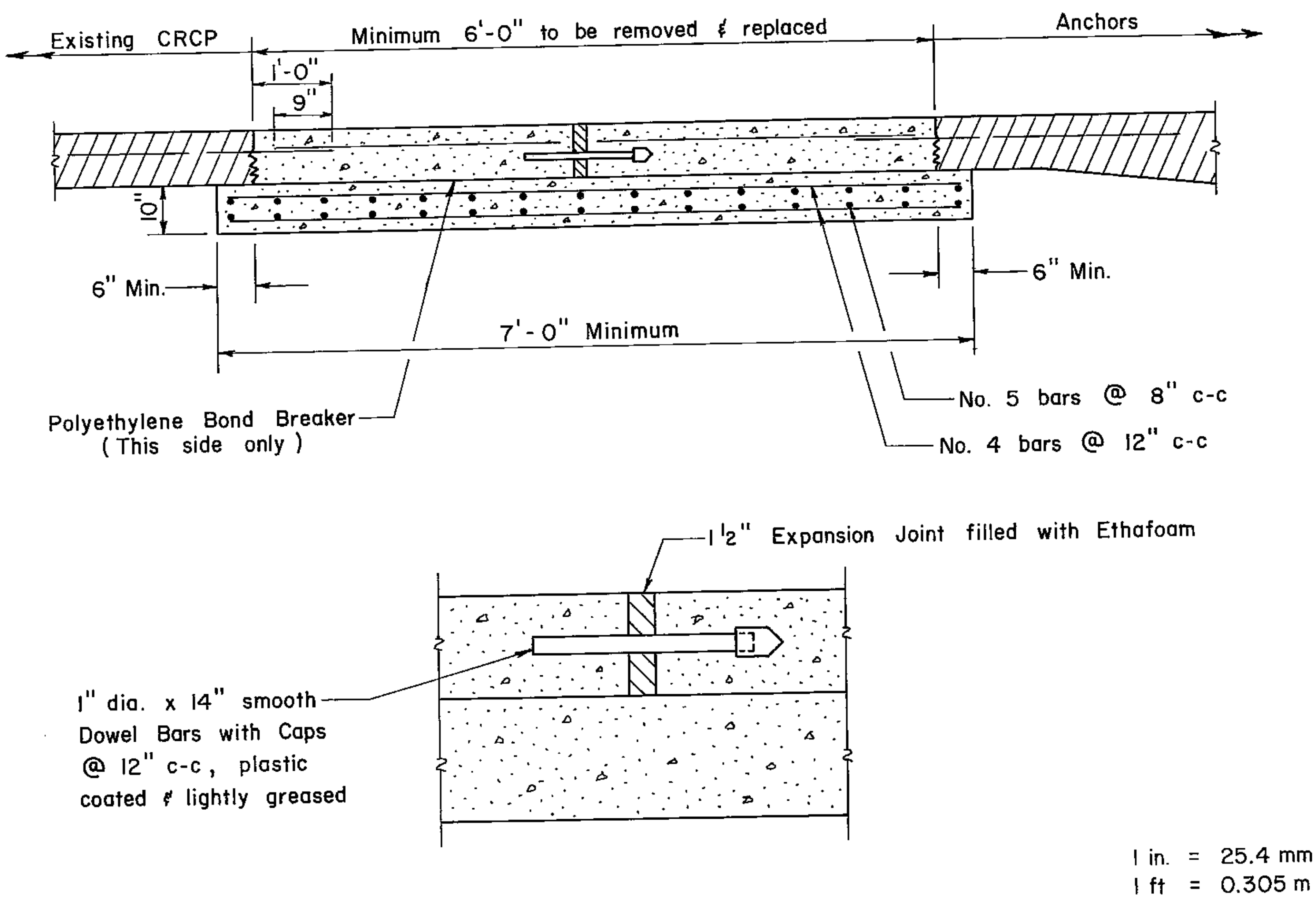


Figure 19. Dowelled Joint For Repairing Distressed Lug Areas.

constructed one lane at a time. With the dowels and sleeper slab for load transfer and the ethafoam to take the expansion and prevent intrusion of compressibles, this joint should perform well while at the same time being less costly. The dowelled design also has the advantage of an exposed expansion material that can be inspected periodically to determine whether the joint is functioning properly.

Terminal Joint System

The wide-flange beam terminal joint systems constructed in 1970 and 1971 have been performing satisfactorily. They are providing a smooth transition between the abutting pavements and have excellent shear transfer. The anchor system is not very effective when the embankment is of cohesionless soil. In this type of soil the wide-flange beam terminal joint system is the main effective tool. No seasonal maintenance of the beam joints has been required or carried out. The sealant used in the pavement notch eventually worked out of the notch; however, no apparent problems have developed from the loss of the sealant.

SUMMARY OF PRINCIPAL FINDINGS

Observation of the behavior of the Illinois experimental lug anchors and wide-flange terminal joints has indicated the following general trends.

Anchor System

1. Based on limited data the average annual winter-to-summer movements of lug anchor systems did not exceed 3/4 in.(19 mm) at any of the experimental locations. Slightly greater winter-to-summer movements occurred in northern Illinois as compared with southern Illinois. This slight difference may be attributed to the difference in mean temperature variations between northern and southern Illinois.

2. Although the annual winter-to-summer lug movements were less in southern Illinois, the data indicate that the pavement ends in southern Illinois tended to grow more than those in northern Illinois. The reasons for the greater growth rate in southern Illinois are not clear at this time. The type of embankment soil may be a contributing factor, as may be the climatic differences and number of lugs. The differences in movements and growth resulting from the different number of lugs appear to be minor. All combinations appear to have been effective in restricting the movement of the pavement ends to less than 3/4 in. (19 mm).
3. The frequency of transverse cracks apparently has had no significant effect on the movements of the anchor systems. At most locations fewer cracks formed within the lug area than formed within the CRC pavement adjacent to the lug area. The number of cracks increased with age, with most of the cracks usually developing in the early years after construction.
4. Most of the lug anchor installations have been effectual in restraining the end movements of CRC pavements. At a few locations throughout the State, problems have developed with dips forming between lugs, creating a rough riding surface. Most problems have occurred about five years after construction at locations with 4 lugs at 40 ft (12.2 m). Few problems have developed at locations with 3 lugs spaced at 20 ft (6.1 m); however, the 3-lug systems, constructed since 1969, have not been in place as long as the 4-lug systems.

The dips between lugs are apparently caused by either a rotation of the lugs or a differential settlement of the embankment or a combination of both. These problems have been alleviated by cutting a 4-in. (102-mm) pressure relief joint and in some instances by mud-jacking or overlaying the undulated area. However, at most locations, the anchor lugs have performed satisfactorily without extraordinary maintenance.

5. The installation cost of the wide-flange beam terminal joint system is about 25 percent less than the cost of the anchor system.

<u>Terminal Joint System</u>

1. The average maximum movement of the slab at any wide-flange terminal joint has been less than 3/4 in. (19 mm). No significant relationship has been established between the amount of the annual movement and age, but there is a tendency for the free end to slightly move with time toward the beam.
2. Other than a single crack developing in the pavement at or near the end of the sleeper slab in 8 out 10 cases, no cracks have developed between the end of the CRC slabs and a distance from the end varying between 63 to 148 ft (19.2 to 45.1 m). The remainder of the slab has developed cracks in a normal manner, with cracks being relatively uniformly spaced and tight at the surface. Most cracks within 300 ft (91.4 m) of the ends developed within the first year after construction. During the four years of observations, the cracks appeared to have little effect on the performance of these joints.
3. The wide-flange beam terminal joints constructed in 1970 and 1971 appear to be performing satisfactorily. They are providing a smooth transition between the abutting pavements and have excellent shear

transfer. In all cases the polyurethane sealant has worked out of the pavement notch; however, no apparent problems have developed because of the absence of the sealant. The joints can probably be constructed without the sealant with no detrimental effects.

4. A direct comparison of the behavior of the wide-flange joints and the anchor lugs is difficult to derive from the data compiled during this study, because the data from the anchor lugs cover a longer and different time period than the data from the wide-flange joints. However, the data from the wide-flange joints suggest that this type of terminal treatment is an effective method of accommodating the movement at the ends of the pavements at a lower cost than restraining the movement with anchor lugs.

RECOMMENDATIONS FOR IMPLEMENTATION

Based on the finding that all combinations of number of lugs and lug spacing appeared to be effective in restricting movements of pavement ends, the standard design was changed in 1969 from 4 lugs at 40 ft (12.2 m) to 3 lugs at 20 ft (6.1 m). The change resulted in a 25 percent cost saving with no apparent effect in performance.

Based on the finding that the wide-flange beam terminal joint has performed well over a seven-year period, and effectively accommodated movements of the ends of CRC pavements at a lower cost than restraining the movements with lugs, it is recommended that the wide-flange beam joint replace the anchor lug system as the standard terminal treatment for CRC pavements.

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